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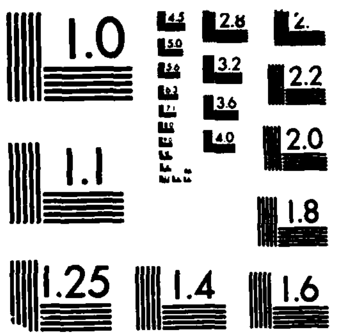

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DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

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TECHNICAL REPORT D-88-2

VERIFICATION OF PROCEDURES FOR DESIGNING DREDGED MATERIAL CONTAINMENT AREAS FOR SOLIDS RETENTION

by

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Environmental Laboratory

DEPARTMENT OF THE ARMY
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Design procedures for hydraulically filled dredged material containment areas to ensure solids retention were initially developed during the Dredged Material Research Program. These procedures involve performing laboratory column settling tests to define settling properties of dredged material and to provide a basis for containment area design. Since their initial development, these procedures have been refined by additional laboratory and field studies conducted as part of the Dredging Operations Technical Support Program and the Long-Term Effects of Dredging Operations Program.

This report provides verification data on the accuracy of column settling tests used in describing the settling behavior of dredged material disposal areas. Results of settling tests conducted by the Waterways Experiment Station over a 6-year period are presented. Predictions of zone, flocculent, and compression settling behavior are compared with

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18. SUBJECT TERMS (Continued).

ADDAMS	Design criteria	Flocculant	Zone
Compression	Dredged material	Sedimentation	
Containment areas	Dredging	Settling	

19. ABSTRACT (Continued).

observed field behavior for purposes of verification. Levels of effluent suspended solids predicted by flocculent settling tests and associated design procedures compared well with effluent suspended solids monitored during containment area operations. Zone and compression settling tests were found to closely agree with field results, but more field data are needed to expand use of these procedures to a wider range of operating conditions.

Appendixes to this report provide detailed procedures for performing the laboratory tests and for designing containment areas based on laboratory settling data. The Automated Dredging and Disposal Alternatives Management System (ADDAMS) was used to analyze all of the laboratory data and to generate design data for comparison to field results.

PREFACE

This task was coordinated through the Dredging Operations Technical Support (DOTS) Program at the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The DOTS Program is sponsored by the Office, Chief of Engineers, US Army, through the Dredging Division of the Water Resources Support Center, Fort Belvoir, Va. DOTS is managed by the WES Environmental Laboratory (EL) through the Office of the Environmental Effects of Dredging Programs (EEDP).

Field and laboratory verification were performed by the Water Resources Engineering Group (WREG), of the Environmental Engineering Division (EED), EL. This report was written by Mr. Daniel E. Averett and Mr. Roy Wade of the Water Supply and Waste Treatment Group, EED, and Dr. Michael R. Palermo, Chief, WREG. The work was conducted under the direct supervision of Dr. Raymond L. Montgomery, Chief, EED, and under the general supervision of Dr. John Harrison, Chief, EL. Significant contributions in the conduct of the laboratory and field work were made by Dr. Paul Schroeder, Dr. F. D. Shields, Mr. Don Hayes, Mr. Richard A. Shafer, Ms. Cheryl Lloyd, Ms. Kathy Smart, and other personnel of the EED. Managers of EEDP during the conduct of this study were Mr. Charles C. Calhoun and Dr. Robert M. Engler. Mr. Thomas R. Patin was coordinator of the DOTS Program.

Commander and Director of WES was COL Dwayne G. Lee, CE. The Technical Director was Dr. Robert W. Whalin.

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* Appendix D is on microfiche and is enclosed in a pocket attached to the inside back cover.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4047.	square metres
acre-feet	1233.482	cubic metres
cubic feet per second	0.2832	cubic metres per second
cubic yards	0.7646	cubic metres
feet	0.3048	metres
feet per hour	0.3048	metres per hour
feet per second	0.3048	metres per second
gallons (US liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
pounds (mass)	0.4535924	kilograms
pounds per cubic foot	16.019	grams per litre
pounds per cubic foot	16018.463	milligrams per litre
pounds per hour-square feet	4882.428	grams per hour-square metres

VERIFICATION OF PROCEDURES FOR DESIGNING DREDGED MATERIAL CONTAINMENT AREAS FOR SOLIDS RETENTION

PART I: INTRODUCTION

Background

1. Placement of dredged material in confined disposal areas has increased in recent years due to constraints on open-water disposal. Confined disposal areas are created by enclosing an area with a retaining dike. Dredged material is usually pumped into the area hydraulically by pipeline dredge or by using hopper dredges or scows with pump-out capabilities.

2. Confined disposal areas are used to retain dredged material solids, while in most cases allowing the carrier water to be released from the disposal area. The two objectives inherent in the design and operation of a confined disposal area are (a) to provide adequate storage capacity to meet long-term dredging requirements, and (b) to attain the highest possible efficiency in retaining solids during the dredging operation in order to meet effluent suspended solids requirements. These considerations are basically interrelated and depend upon effective design, operation, and management of the disposal area.

3. Procedures for designing confined disposal areas were initially developed during the Dredged Material Research Program (DMRP) (Palermo, Montgomery, and Poindexter 1978). These procedures required data from column settling tests to define the settling properties of the material to be dredged. Refinements to the initial test procedures were developed, and verification studies were conducted as a part of the Disposal Operations Technical Support (DOTS) Program. Additional refinements were developed as a part of the Long-Term Effects of Dredging Operations (LEDO) Program.

4. Procedures for conducting flocculent and zone settling column tests are described in detail in Appendix A. Design procedures for determining the surface area required for effective zone settling, the retention time required for removal of effluent suspended solids, and the volume required for initial storage are described in Appendix B.

5. During the development of laboratory and design procedures, a variety of sediments were tested. Field data on dredged material settling behavior were also collected at several sites as a part of this effort. Additional sediments were tested in support of ongoing planning and design studies by several District offices. In all, 28 sediment samples were tested at the US Army Engineer Waterways Experiment Station (WES) between 1978 and 1984. Data available from these laboratory and field studies serve as a verification of the testing and design procedures.

Purpose and Scope

6. The purpose of this report is to present data to verify the accuracy of column settling tests in describing the settling behavior of dredged material hydraulically placed in confined disposal areas. Results of settling tests conducted by WES over a 6-year period are presented. These tests involved 28 sediment samples collected at a total of 17 test sites. Predictions of zone, flocculent, and compression settling behavior based on the test results are compared with observed field behavior for purposes of verification.

Dredged Material Settling Behavior

7. Dredged material placed in disposal areas by hydraulic dredges or pumped into disposal areas by pump-out facilities enters the disposal area as a slurry (a mixture of solids and overlying water from the dredging site). Settling refers to those processes in which the dredged material slurry is separated into supernatant water of low solids concentration (to be discharged) and a concentrated slurry (to be retained). Laboratory settling tests provide data for designing the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for the dredged solids.

Settling processes

8. Settling types. The settling process can be categorized according to four basic classifications (Thackston 1972, Montgomery 1979, and Montgomery, Thackston, and Parker 1983): (a) discrete settling, in which the particle maintains its individuality and does not change in size, shape, or

density during the settling process, (b) flocculent settling, in which particles agglomerate during the settling period with a change in physical properties and settling rate, (c) zone settling, in which the flocculent suspension forms a lattice structure and settles as a mass (interparticle forces hinder settling of neighboring particles, and a distinct interface between the slurry and the supernatant water is exhibited during the settling process), and (d) compression settling, in which settling occurs by compression of the lattice structure. Figure 1 is a conceptual illustration of these settling processes. All of the above sedimentation processes occur in a disposal area and any one may control the design of the disposal area.

9. Factors governing settling. The important factors governing the sedimentation of dredged material are the initial concentration of the slurry and the flocculating properties of the solid particles. Because of the extremely high influent solids concentration and the tendency of fine-grained particles to flocculate, either flocculent or zone settling behavior normally governs sedimentation in containment areas (Montgomery 1978). Sedimentation of freshwater sediments at slurry concentrations less than 100 g/ℓ can generally be characterized as flocculent settling. As slurry concentrations are increased, the sedimentation process may be characterized as zone settling. Discrete settling describes the sedimentation of sand particles and fine-grained sediments at very low concentrations. Compression settling occurs in the lower layers of settled material for both the flocculent and zone settling cases. As more settled material accumulates, excess pore pressures develop in the lower layers and compression settling transitions into consolidation as the excess pore pressures dissipate.

10. Zone versus flocculent settling as a function of salinity. The tendency of a fine-grained dredged material slurry to exhibit either zone or flocculent settling behavior in the initial stages of settling is strongly influenced by the presence of salt as a coagulant. If the salinity is less than 3 ppt, indicative of freshwater conditions, flocculent settling behavior normally describes the initial settling, and no clearly defined interface is seen. If the salinity is greater than 3 ppt, indicative of brackish or saltwater conditions, zone settling behavior normally describes the initial settling, and a clear interface between the clarified supernatant water and the more concentrated slurry is evident. For the zone settling case, some of the fine particles remain in the supernatant water as the interface falls.

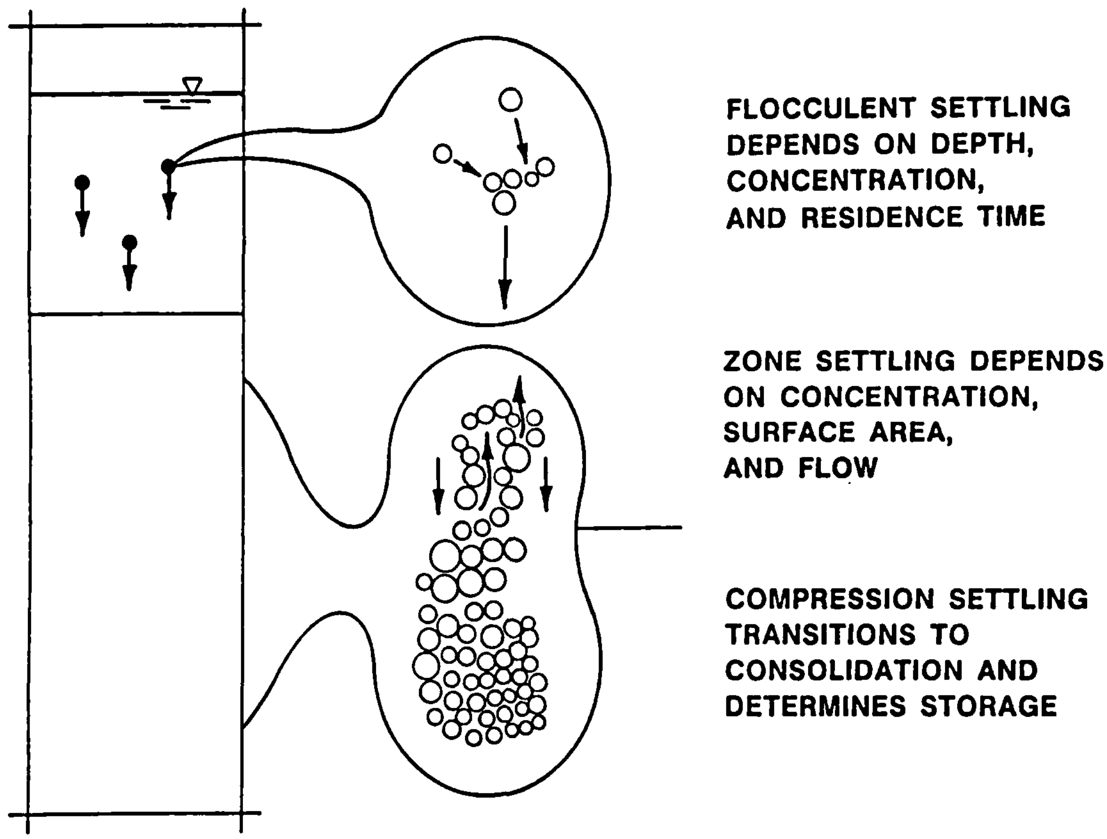


Figure 1. Conceptual illustration of dredged material settling processes

Flocculent settling behavior describes the settling of these fine particles from the supernatant.

Development of Testing and Design Procedures

Initial experimental studies

11. Studies in the early 1970's examined discrete settling theories as a means to describe settling behavior of dredged materials. Krizek, Fitzpatrick, and Atmatzidis (1976) proposed discrete settling design in conjunction with studies on the filtration of effluents. Mallory and Nawrocki (1974) had earlier proposed similar designs as part of an overall evaluation of solid-liquid separation technology as related to dredged material. Montgomery (1979) later showed that either flocculent or zone settling, not discrete settling, describes the sedimentation behavior of fine-grained dredged material.

12. Montgomery developed a column settling test to describe either flocculent or zone settling behavior of dredged material slurries. The tests provide numerical values for design criteria, which can be used to design the containment area. It is important that the sediment slurry being tested have characteristics in the settling column similar to those that it will have in the containment area. This becomes increasingly difficult to assure as the sediment slurry becomes more flocculent and as solids concentrations increase.

13. Montgomery conducted column tests using several sediments to develop appropriate test procedures and to characterize the sedimentation regimes describing dredged material slurries. Column diameter, column (initial slurry) height, and initial slurry concentration were varied in the test series.

14. Results indicated that the settling velocity decreased with increasing initial slurry concentration. As part of this series, Montgomery conducted tests directly comparing the settling characteristics of a sediment sample taken prior to dredging with those of the same material after discharge into a containment area. Regression analysis performed on data for settling velocity versus concentration indicated no significant difference. Therefore, settling tests on sediment samples taken prior to dredging were found to be valid for describing the settling behavior that a material would exhibit within a containment area.

15. Montgomery also found that wall effects apparent in the multidiameter tests were probably due to the relatively high concentrations of the solids in dredged material slurries. Bridging effects in small-diameter columns tended to increase settling velocities. At high slurry concentrations, the upward flow of water displaced from the bottom of the column in channels along the column wall tended to decrease friction between the wall and the solid mass and thus to increase settling velocity. Montgomery's data indicated that wall effects are significant at slurry concentrations greater than about 50 g/ℓ for column diameters less than 6 in. Therefore, he concluded that columns 8 in. or more in diameter should be used in tests for sedimentation area design.

16. The multiheight test data indicated that, at concentrations less than about 50 g/ℓ, initial slurry height had little effect on settling velocity. At greater slurry concentrations, column height had a pronounced effect, with significantly increased settling velocities resulting from higher slurry

heights. Montgomery concluded that tests for sedimentation design should be conducted at a slurry height selected to match the depth expected in the field.

Recommended settling column

17. The standard test column recommended by Montgomery for routine evaluation of dredged material sedimentation is an 8-in.-diam sectional column with side extraction valves. A schematic diagram of the column is shown in Figure 2. Field verification work initially documented by Montgomery (1979) has shown that the column test procedure adequately simulates the field settling behavior of fine-grained dredged material.

Development of design procedures

18. Montgomery developed procedures for containment area design and evaluation based on the works of Coe and Clevenger (1916), McLaughlin (1959), Thackston (1972), Dick and Ewing (1967), Yoshioka et al. (1957), and Vesilind (1968). The testing and design procedures for flocculent settling proposed by Montgomery rely on the measurement of suspended solids concentrations within the test column as a function of depth and time. This procedure allows determination of simulated suspended solids "gradients" within the supernatant waters. These data are then used to establish required retention times for a desired suspended solids removal. The determination of suspended solids gradients provides desirable information on the composition of supernatant waters for this settling case.

19. Design procedures for zone settling are based on the measurement of the interface position as a function of time and the subsequent calculation of settling velocities. Montgomery states that the zone settling design procedure will result in effluent suspended solids levels of 1 to 2 g/ℓ. However, the testing procedures for zone settling do not provide any information on the solids or contaminant composition of supernatant waters.

Refinements to initial column test procedures

20. Pilot test. The column test procedures developed by Montgomery (1978) called for observing the settling behavior exhibited in the 8-in. column and initiating either flocculent or zone settling design procedures, depending on the behavior exhitited by the suspension. Based on the experience gained by testing a variety of materials, a pilot test was found to be a useful indicator of settling behavior that could be performed prior to the

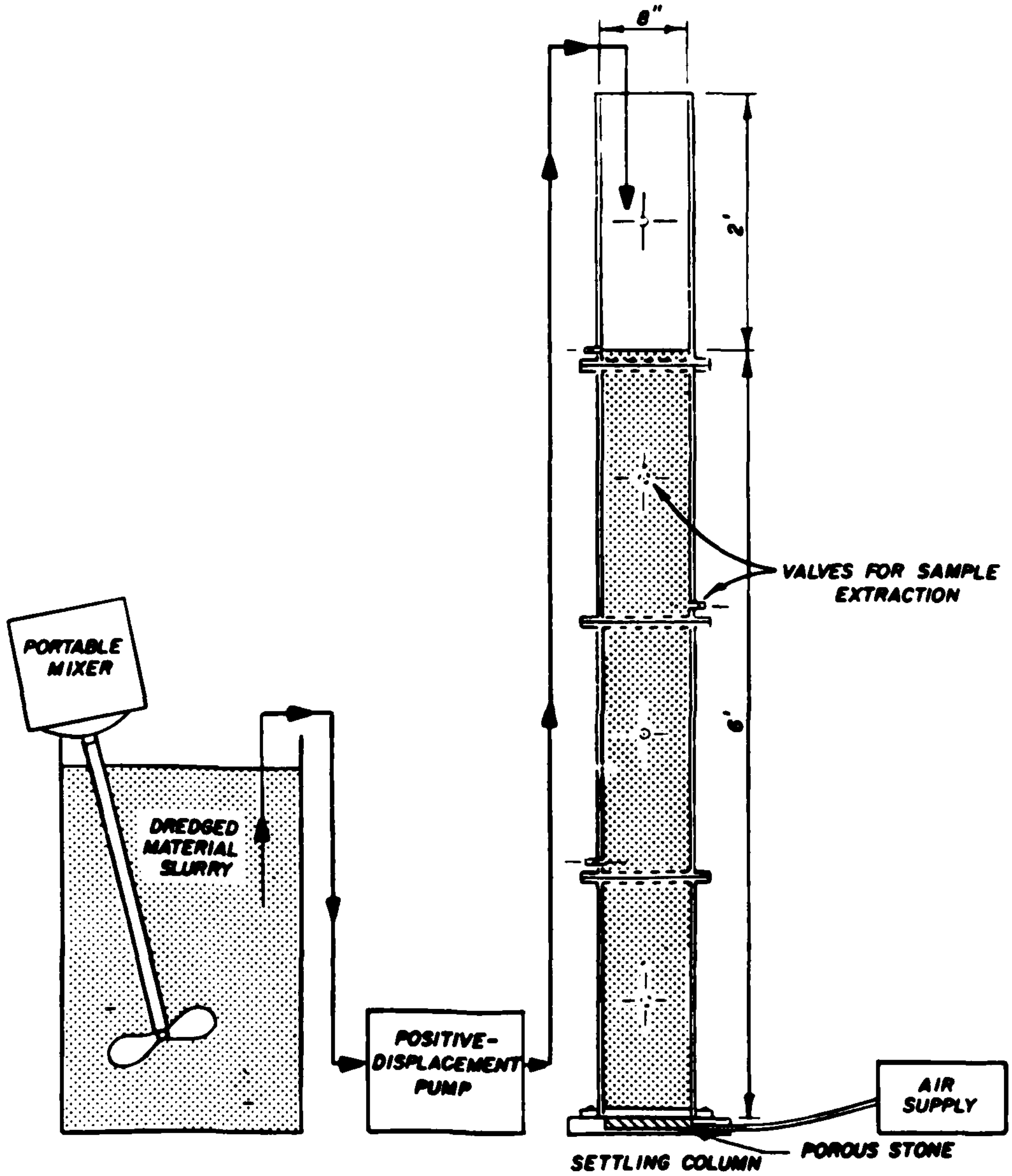


Figure 2. Schematic diagram of apparatus for settling tests (Montgomery 1978)

test in the 8-in. column. Once the pilot test determines what type of settling will occur, the procedures for the 8-in. column test can be planned in advance. In some cases, advance knowledge of settling behavior at a representative slurry concentration can influence the sequence of testing.

21. The pilot test consists simply of placing the slurry to be tested in a 1- to 4-ℓ graduated cylinder at a desired concentration (usually 150 g/ℓ to simulate the average inflow concentration to a confined disposal area). The slurry is allowed to settle, and the observation is made as to whether or not an interface will form.

22. Hydraulic separation of coarse and fine materials. The initial test procedures developed by Montgomery (1978) called for physical separation of the coarse fraction (> No. 40 sieve) from the fine fraction (< No. 40 sieve) prior to initiation of the test. This requirement is based on the fact that coarse material settles quickly near the inflow point and is naturally separated from the fine material. However, experience gained on several sediments in the laboratory proved this to be a highly labor-intensive practice. Hydraulic separation of coarse material was therefore adopted as an alternate method of separation. Hydraulic separation is accomplished as follows:

a. The pilot test results are examined, and a rough approximation of the fraction of sands and coarser material is made. If a zone settling test series is needed, the 8-in. column tests will be started at higher concentrations and subsequent tests will be conducted at lower concentrations. This information is used to estimate the approximate concentration needed for the slurry prior to separation.

b. Sediment and water are mixed in a 55-gal drum to a slurry concentration equal to the expected inflow concentration in the confined disposal area (150 g/ℓ in the absence of better data).

c. Sands and coarser material will settle to the bottom of the drum during the mixing process because the mixing energy of a mechanical mixer is insufficient to resuspend the coarse material.

d. While the mixing action is maintained, the finer slurry is pumped into a second 55-gal drum. This separated slurry is then used for the column settling tests.

Refinement of procedures for predicting effluent suspended solids

23. Dredged material slurries that undergo zone settling form a clearly defined interface between the settled material and the clarified supernatant. The column settling test procedures and design procedures initially developed under the DMRP allowed the designer to determine a surface area required for effective zone settling to occur under given flow conditions. However, the DMRP procedures did not allow a prediction of the effluent suspended solids concentrations for the zone settling condition.

24. Palermo (1986) conducted a study under the LEDO Program which resulted in a refinement of the DMRP procedures and which will allow prediction of effluent suspended solids concentrations for the zone settling case. This study was conducted because of the need for a method of predicting chemical effluent quality at confined disposal sites.

25. Laboratory tests were conducted on sediments using the standard 8-in.-diam settling column; however, test procedures were modified. Sediments exhibiting zone settling behavior were tested, and samples were taken from the supernatant water through the side extraction ports on the column. These tests were conducted in order to define the settling behavior of residual particles which initially remained suspended in the supernatant water. These studies determined that the particles initially remaining in the supernatant water settled in accordance with flocculent settling behavior.

26. Palermo subsequently developed a refined flocculent settling data analysis procedure for the supernatant particles similar to that initially developed by Montgomery for slurries exhibiting flocculent settling. The experiments conducted by Palermo indicated that several settling processes could be occurring simultaneously in a dredged material disposal area. These include

- a. Compression settling in the lower layers of settled solids.
- b. Zone settling in the upper layers of settled solids.
- c. Flocculent settling of residual particles in the supernatant waters above the interface.

PART II: SEDIMENT SAMPLING AND CHARACTERIZATION

Sampling Sites

27. Settling column tests and field investigations described in this report were performed on sediment samples collected from the 17 sites illustrated in Figure 3. These sites, scattered over the eastern half of the US, represent both coastal (saltwater) and inland (freshwater) harbors. For 5 of the 17 sites (Indiana Harbor, Mobile Harbor, Norfolk Harbor, Yazoo River, and Savannah Harbor) tests were run for multiple sediment samples that were either collected from more than one station within the harbor or collected at different times for different projects. Field data for containment areas were collected during dredging operations at Mobile, Yazoo River, Savannah, Norfolk, Black Rock, Kings Bay, and Hart-Miller Island. These field data were used to verify and refine the procedures previously proposed (Montgomery 1978 and Palermo 1984) for the design of containment areas. Table 1 lists the harbor sites, the sampling station identifications where different sediments from the same site were tested, how the sediment samples were evaluated or tested, and the types of settling data produced.

Sediment and Water Sampling

28. A sample that is characteristic of the sediment-water slurry discharged from a dredge pipeline is required to conduct testing procedures for the design of dredged material containment areas. Montgomery (1978) showed that settling tests performed on sediments prior to dredging provided settling property data similar to that from tests performed on those sediments discharged as dredged material slurry. Since design data are usually needed prior to the actual dredging operation, it is convenient to conduct settling tests on slurries prepared in the laboratory from sediment and water samples collected at the site. Most of the settling data discussed in this report resulted from tests conducted on laboratory-prepared dredged material slurries.

Sampling equipment

29. Channel sediments evaluated for this study were generally sampled using grab-type samplers such as those described by Palermo, Montgomery, and

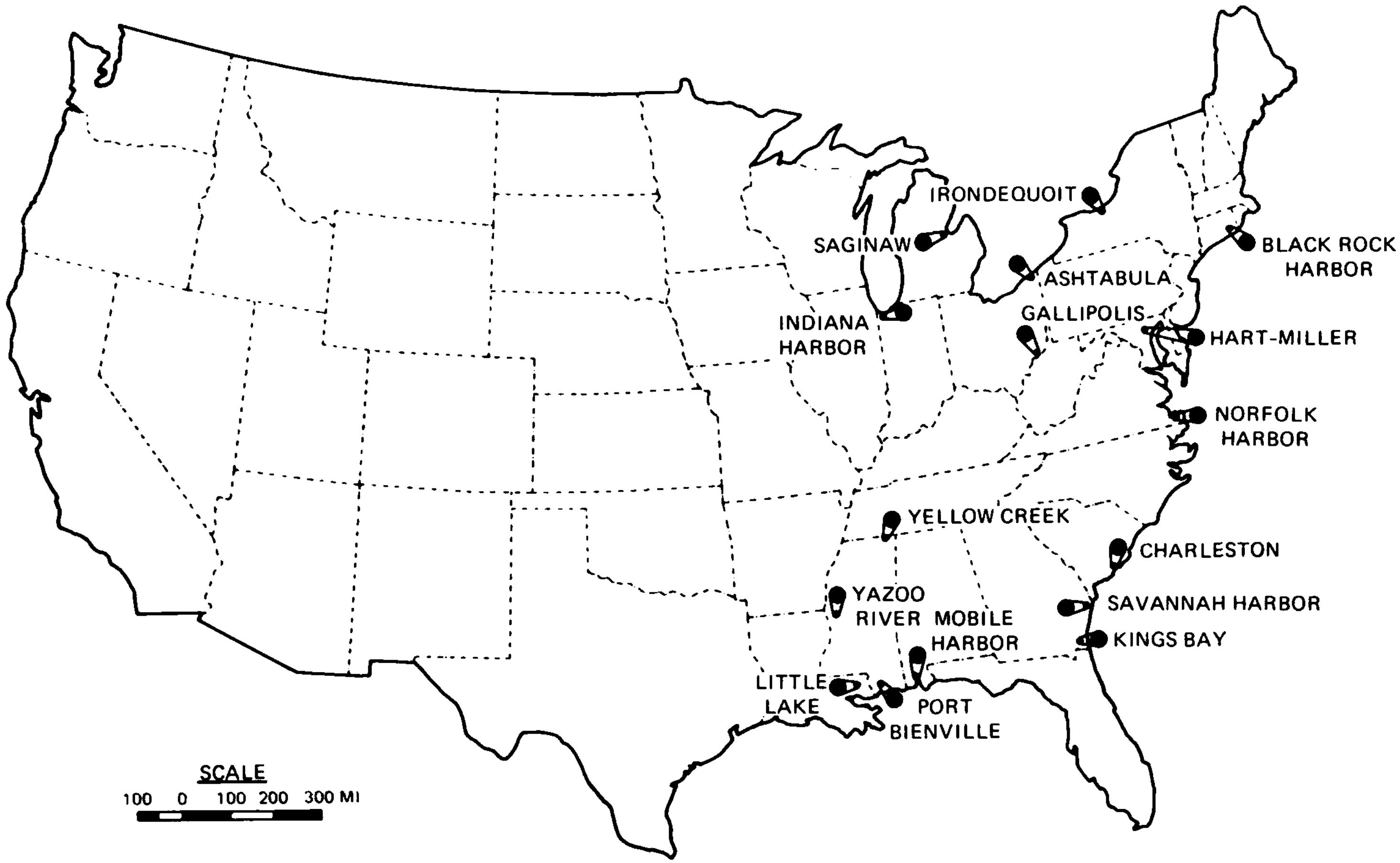


Figure 3. Location of projects used in field and laboratory investigations

Table 1

Sediments Evaluated by Settling Column Tests

Site No.	Site Name	Year Tested	Laboratory Settling Tests* Zone	Laboratory Settling Tests* Compression	Laboratory Settling Tests* Flocculent	Field Tests** Effluent Suspended Solids	Field Tests** Initial Storage Volume
1	Ashtabula Harbor	1984	X	X	X		
2	Black Rock Harbor	1982	X	X	X	X	X
3	Charleston Harbor	1981		X			
4	Fowl River	1977	X				
5	Gallipolis Lock	1983			X		
6	Hart-Miller Is.	1984	X	X	X		
7	Indiana Harbor	1979	X	X	X		
8	Indiana Harbor	1984		X	X		
9	Irondequoit Bay	1981	X	X	X		
10	Kings Bay	1983		X	X		
11	Little Lake	1981	X	X			
12	Mobile Harbor	1978	X	X			X
13	Mobile Harbor-Sta 28	1983		X	X	X	
14	Mobile Harbor-Comp.	1983			X	X	
15	Norfolk Harbor-1B	1980	X	X			
16	Norfolk Harbor-16B	1980	X	X			
17	Norfolk Harbor-31B	1980		X			
18	Norfolk-55 Channel	1981	X	X			
19	Norfolk Harbor	1983			X	X	
20	Port Bienville	1981	X	X			
21	Saginaw Harbor	1983			X		
22	Savannah Harbor	1981	X	X			
23	Savannah Harbor	1982		X	X		
24	Savannah Harbor	1983			X	X	
25	Yazoo River	1978		X	X	X	
26	Yazoo River	1979			X		
27	Yazoo River	1980		X	X		
28	Yellow Creek	1982			X		

* Laboratory tests were conducted to define zone, compression, and/or flocculent settling.

** Field data were collected on effluent suspended solids and/or initial storage volumes.

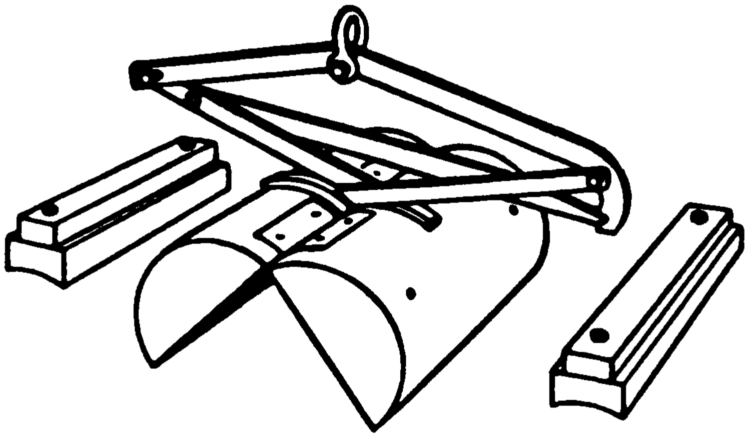
Poindexter (1978). Samplers most often used were the Petersen dredge, the Shipek dredge, and the Phleger tube sampler, all illustrated in Figure 4. Exceptions to this were at Savannah Harbor, where a diving team collected the sediment samples directly, and at Indiana Harbor in 1978, where a small clamshell bucket was used. Grab samples have proven to be adequate for obtaining sediment samples for maintenance dredging projects. New-location dredging through undisturbed consolidated sediments may require more conventional boring techniques.

30. Water samples were sometimes collected at the test site along with the sediment samples. In these cases, the water and sediment from the test site were used to prepare the laboratory dredged material. A small pump was usually used, so that water could be withdrawn from an elevation near the sediment-water interface. In other cases, water was prepared in the laboratory to match the salinities measured in the field.

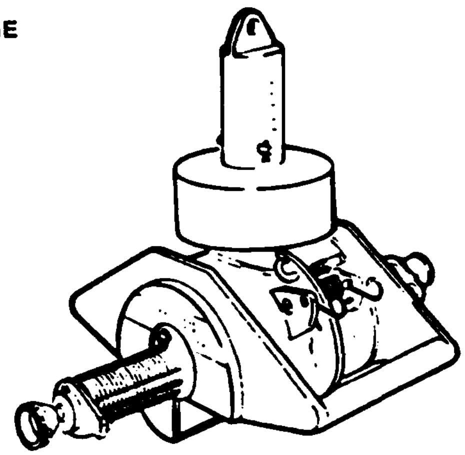
31. Petersen dredge. The Petersen dredge has been used extensively for collecting sediment samples. This sampler has a system of levers to keep the scoop open while the sampler is lowered to the bottom. As the sampler comes to rest on the bottom, the tension in the retrieval line is relaxed, the trip lever drops, and the sampler is ready to obtain the sample. After the trip lever has been released, tension is again applied to the retrieval line. During this time, the jaws slowly shut, enclosing the sample within the scoop. The Petersen dredge is a versatile sampler that will sample a wide range of sediments, from fluffy harbor sediments to dense sand deposits in rivers. The Petersen dredge weighs 39 lb empty, with additional weights available to provide a total weight of 93 lb. The dredge samples 144 sq in. to a depth of about 12 in., depending on the consistency of the bottom.

32. Shipek dredge. The Shipek dredge utilizes two concentric half cylinders to form the sample scoop. The sampler is lowered to the bottom, where a weight releases the triggering mechanism. The scoop gathers a sample as it rotates through a half-circular arc under the force of springs. The sampler is then hoisted to the water surface, where the scoop is released and the sample is transferred to a container. This sampler obtains a sample from an area approximately 8 in. by 8 in. to a depth of about 4 in. The empty weight of the Shipek dredge is approximately 150 lb.

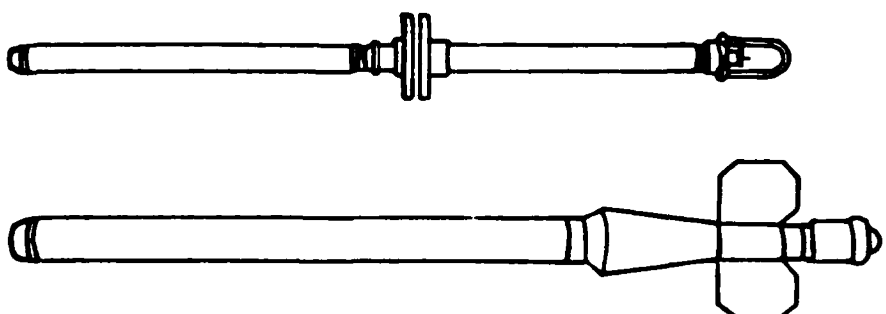
33. Phleger tube sampler. The Phleger tube sampler, often called a harpoon sampler, is widely used for obtaining samples from the upper portion



PETERSEN DREDGE



SHIPEK DREDGE



PHLEGER TUBE

Figure 4. Sediment samplers

of underwater deposits. Because it obtains its penetrating force from its weight and from pushing by operators in a boat, it must necessarily be quite heavy without being awkward to manipulate. The harpoon is available with adjustable weights in the range of 17 to 77 lb and in fixed weights in excess of 90 lb.

Sampling rationale

34. Procedures for sediment sample collection, handling, and preservation must minimize sample contamination and preserve the physical integrity of the samples prior to testing. Plumb (1981) states that the value of data obtained from any sampling program is dependent on (a) collecting representative samples, (b) using appropriate sampling techniques, and (c) adequately preserving the samples. The first requirement regarding representative samples is especially difficult for sediments and dredged material because of the usually large spatial variation. Plumb establishes the following criteria to define the representative nature of a sample:

- a. The area to be sampled must be clearly defined.
- b. The sampling locations should be randomly distributed within the area.
- c. Replicate samples should be collected from each location, unless variability has been established previously.

35. Random locations within the desired channel areas were sampled and composited to assure a representative material for laboratory testing. Portions of the sediment and water sampled were used for purposes of sediment characterization.

36. For most of the projects, sampling was conducted so as to provide an areal average representative of the area to be dredged. Samples were then composited for purposes of physical characterization and column settling tests. For some of the projects, samples were taken at planned locations corresponding to positions of the operating dredge at the time confined disposal sites were sampled. In this way, sediment samples taken from the channel were more representative of material sampled during subsequent field evaluation studies.

Project Descriptions

37. Descriptions of each field site listed in Table 1 and the scope of each investigation are presented below in alphabetical order. The level of detail in the descriptions will vary among the sites because some investigations included sediment characterization, settling tests, design, and field evaluations, while other investigations included only one or two of these tasks. These project descriptions were taken from the original reports prepared for the respective investigations.

Ashtabula Harbor

38. Ashtabula Harbor is located in eastern Ohio on Lake Erie. A series of zone settling tests, a 13-day settling test for estimating initial storage requirements, two flocculent settling tests for estimating effluent suspended solids concentrations, and sediment characterization tests were performed in response to a request from the Buffalo Engineer District. Sediment samples were collected by the Buffalo District, and WES ran the tests. Test results were furnished to the Buffalo District for design of the Ashtabula Confined Disposal Project.

Black Rock Harbor

39. Black Rock Harbor, located near Bridgeport, Connecticut (Figure 5), is an active harbor serving both commercial and recreational navigation. The project consists of a channel with an authorized channel depth of 18 ft and channel widths of 200, 150, and 100 ft, moving upstream. The channel was dredged in 1955 to a depth of 18.0 ft, with an allowable overdredge of 1 ft. Shoaling since that time had reduced the channel depth to approximately 13.0 ft, with isolated shoaling resulting in depths as little as 9.0 ft. Approximately 425,000 yd^3 of sediment were removed from the channel in late 1983 to restore the channel to authorized dimensions (Palermo 1984).

40. The Black Rock Harbor Project was the selected site for the Corps of Engineers (CE) Field Verification Program (FVP), designed as a cooperative effort between the CE and the Environmental Protection Agency (EPA) to field verify testing procedures for implementing the requirements of Sections 404 and 103 of the Federal Water Pollution Control Act. Through the FVP, promising procedures developed by both the CE and EPA (including the predictive technique considered in this study) were applied at Black Rock Harbor using dredged material from a single maintenance operation. The dredged material

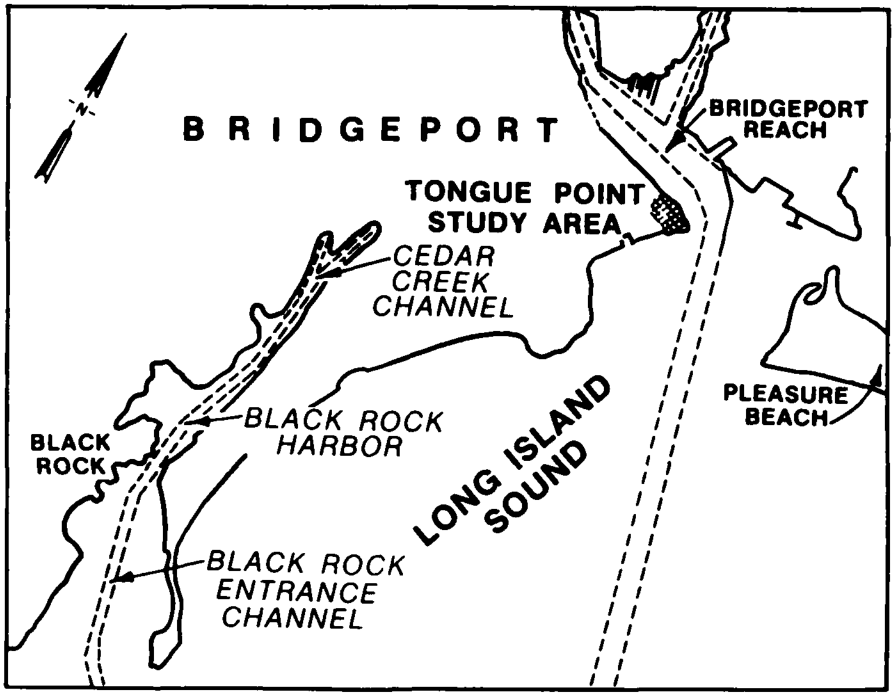


Figure 5. Black Rock Harbor

was placed in both an open-water aquatic site and two confined disposal sites, under both wetland and upland conditions, thus providing an unusual opportunity for direct comparison of the environmental consequences of different disposal conditions on the same material.

41. During March and April, 1982, an extensive sediment sampling program was conducted at Black Rock Harbor. The purposes of the sampling program were to physically and chemically characterize the sediments prior to dredging and to provide samples of sediment for confined disposal site design. The sediment sampling design was based on providing spatial coverage of the area to be dredged and providing sufficient sediment volume for all anticipated laboratory testing.

42. During March, 1982, 10 samples were taken at evenly spaced centerline stations within the channel study reach to determine physical sediment characterization. Samples were taken using a Petersen dredge sampler. Approximately 5 gal of sediment was obtained at each of the 10 stations. A composite of these samples was used in the column settling tests used for the confined disposal site design.

43. During October, 1983, a field investigation was conducted at the Black Rock Disposal Site during dredging operations. Data collection included

mean retention time, effluent suspended solids concentrations, and ponding depth. These data were compared to effluent suspended solids concentration predictions from laboratory flocculent settling tests.

44. Field evaluations at the FVP Site included extensive sampling of the inflow and effluent during the filling operation. The storage volume occupied by the material was determined by surveys and by settlement plates placed within the sites.

Charleston Harbor

45. A settling test was conducted on a composite sample of dredged material taken from the Drum Island Confined Disposal Area in Charleston Harbor. This test was conducted in 1983, along with consolidation tests on the same sample as a part of the DOTS Engineering Verification work unit. No corresponding field data on sedimentation were collected at the site.

Fowl River

46. The Fowl River flows into Mobile Bay about 20 miles south of Mobile, Alabama. The 12.8-acre containment area used in 1977 was equipped with one 8-ft weir to accommodate the flow from the 16-in. dredge used for maintenance dredging at the time of the site investigation. The Fowl River containment area is located in a saltwater environment; however, during periods of high water in the Fowl River, the inflow of fresh water pushes out the saltwater wedge and the site is under freshwater conditions. During the field investigations, the salinity of the sediment carrier water sampled from the hydraulic dredge pipeline was about 1 ppt.

47. This site was used by Montgomery (1978) for the initial development of his design methodology for dredged material sedimentation basins. Channel sediment and dredged material samples were taken for laboratory tests. Suspended solids concentrations were determined at sampling stations within the containment area. Dye tracer tests were performed to determine the actual retention time in the containment area.

Gallipolis Locks

48. The Gallipolis Locks and Dam Replacement Project is located along the Ohio River near Gallipolis, Ohio. To provide the structure and approach channels for this project, approximately 15,000,000 yd^3 of in situ soils must be excavated. The US Army Engineer District, Huntington, West Virginia, requested that WES evaluate excavation by dredging as an alternative to conventional excavation, which would be complicated by an extensive dewatering

requirement. Settling tests were performed to provide necessary data for design of a disposal area not only for the new work-dredged material but also for future maintenance dredging. The disposal area is located in the state of West Virginia, which specified suspended solids concentration discharge standards for disposal area effluent. WES performed a flocculent settling test to further define design requirements for the containment area (Hayes et al. 1985).

Hart-Miller Island

49. WES and the State of Maryland conducted laboratory and field studies at the Hart-Miller Island Disposal Area in 1984. Hart-Miller Island is a 900-acre containment island constructed for disposal of materials from the inner Baltimore Harbor. A settling test was conducted on a composite sample of sediment taken by the Baltimore District. Material dredged from the area was the initial material placed in the Hart-Miller Island Disposal Area. The site was monitored for effluent quality during placement of the material.

Indiana Harbor

50. Indiana Harbor is at the southwest end of Lake Michigan in northwestern Indiana near the Illinois state line and the city of Chicago. Because of its urbanized and industrialized surroundings, sediments in Indiana Harbor are contaminated by conventional and potentially toxic pollutants. The US Army Engineer District, Chicago, has responsibility for maintenance dredging of Indiana Harbor and the upstream Indiana Harbor Canal. Selection and design of a containment area for dredged material are complicated by the need to protect water quality in Lake Michigan, a source of drinking water for millions of people.

51. Settling tests on Indiana Harbor sediment were first reported in 1980 (Myers et al. 1980). Sediment and water samples were collected at three sites and composited. Zone, flocculent, and compression settling tests were performed on this composite sediment sample. Additional sediment samples from the harbor were collected in 1984 to provide site-specific settling data for evaluation of confined disposal alternatives. Flocculent and compression settling data were included in this analysis.

Irondequoit Bay

52. Irondequoit Bay is an embayment of Lake Ontario located near the cities of Irondequoit and Rochester, New York. Settling tests on sediment from this harbor were performed in response to a DOTS request from the US Army

Engineer District, Buffalo. Zone, flocculent, and compression settling tests were performed by WES, and the test data were furnished to the Buffalo District.

Kings Bay

53. Kings Bay, Georgia, is the location for the ongoing development of a major US Navy submarine base. Large quantities of dredged material from channel enlargements have previously been placed in several confined disposal sites adjacent to the channels. Maintenance dredging in channels adjacent to the Crab Island Disposal Area at Kings Bay was performed in December, 1982. Sediments from this project were sampled and used to perform column settling tests. Effluent suspended solids data were collected as part of a routine monitoring requirement throughout the disposal operation and were compared with the column test results from the flocculent settling test.

Little Lake

54. Little Lake is located on the Gulf Coast in St. Tammany Parish, Louisiana, near New Orleans. The US Army Engineer District, Mobile, requested that WES conduct sediment characterization and settling tests for this site under the DOTS Program. Zone and compression settling tests were run, and a preliminary containment area design was furnished to the Mobile District.

Mobile Harbor

55. Mobile Harbor, Alabama, consists of the approach channels from the Gulf of Mexico through Mobile Bay and a 40-ft-deep by 500- to 775-ft-wide channel 4.6 miles up the Mobile River to the Cochran Bridge in northern Mobile. Channels above the bridge extend 2.7 miles into Chickasaw Creek, a tributary to the Mobile River. A map of the project, including channels and other features, is shown in Figure 6.

56. Mobile Harbor is dredged annually to maintain authorized depths in waterways and harbors. Several confined disposal areas located adjacent to the channel have been used to confine the dredged material. The Lower Polecat Bay and the Upper Polecat Bay, or North Blakely, Disposal Sites were in use when settling tests for dredged material were being developed and verified (Montgomery 1978 and Palermo 1984).

57. Three different sediments from Mobile Harbor were subjected to settling column tests. First, Montgomery (1978) ran zone and compression settling tests on sediment samples and on slurry samples collected from the 24-in. pipeline of a hydraulic dredge. A 30-ft by 30-ft test pit was also

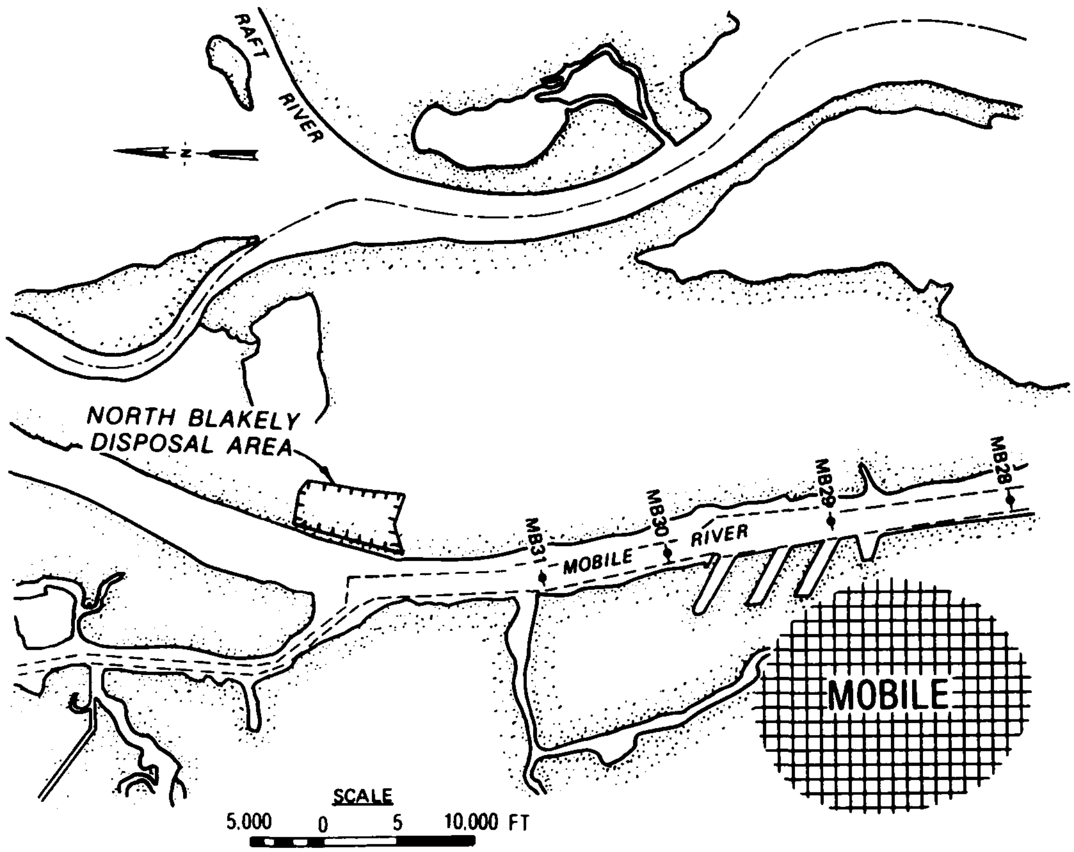


Figure 6. Mobile Harbor, Alabama, showing location of channels and North Blakely Disposal Area

constructed for evaluation of zone and compression settling in the field versus that in the laboratory. Palermo (1984) collected a composite sediment sample from several stations in January 1982 and subjected this sample to a flocculent settling test. This test was part of a study on refining the design methodology for predicting effluent suspended solids concentrations in materials that exhibit zone settling behavior. Palermo (1984) collected additional sediment samples in July, 1982, from Station MB28. Flocculent and compression settling tests were performed on this sediment in the laboratory. Also, during June, 1982, while a dredge was working near Station MB28, a field evaluation of the Blakely Disposal Area was conducted. This study measured influent and effluent suspended solids concentrations, retention time, and water quality parameters. Field results were compared to laboratory predictions for effluent suspended solids concentrations.

Norfolk Harbor

58. Norfolk Harbor, Virginia, is the location of one of the major coal exporting facilities in the US. The Norfolk Harbor Complex consists of 45-ft channels and anchorages which serve both major commercial and naval facilities. A layout of the harbor area is shown in Figure 7.

59. The Craney Island Disposal Area, which serves Norfolk Harbor, has a surface area of 2,500 acres, making it one of the largest such sites in the nation. (See Figure 7.) Plans for the site were developed in the early 1940's to provide a long-term disposal area for material dredged from channels and ports in the Hampton Roads area. Construction of dikes at Craney Island was completed in 1957, and material has since been placed within the disposal area almost continuously, using both direct pipeline discharge and hopper pump-out. Over 142,000,000 yd^3 of dredged material have been placed within the area so far, and maintenance dredging now produces an average of 5,000,000 yd^3 of sediments per year. A management plan (Palermo, Shields, and Hayes 1981) has recently been developed for the Craney Island Disposal Area which provides guidelines on operation and management of the site to prolong its service life.

60. Settling tests were performed on five different sediments from Norfolk Harbor. In April, 1980, separate samples were collected from Stations 1, 16, and 31 (Figure 7). A compression settling test was performed on all three samples, and a zone settling test was performed on Samples 1 and 16. These tests were described in the management plan for the Craney Island Disposal Area. In 1981, sediment samples were collected from the Norfolk Harbor 50-ft channel project and were tested for zone and compression settling. Finally, in 1983, sediment and water were collected from the Norfolk Harbor 45-ft channel. This material was evaluated in the laboratory by the flocculent settling test on the supernatant above a zone settling interface. During 13-16 February 1983, field data, including influent and effluent suspended solids concentrations and retention times, were collected during dredging operations at the Craney Island Disposal Area. Comparison of these data with the laboratory data is reported in Part IV.

Port Bienville

61. Port Bienville is located on the Gulf Coast near Bay St. Louis, Mississippi. The US Army Engineer District, Mobile, requested that WES conduct sediment characterization and settling tests for this site under the DOTS

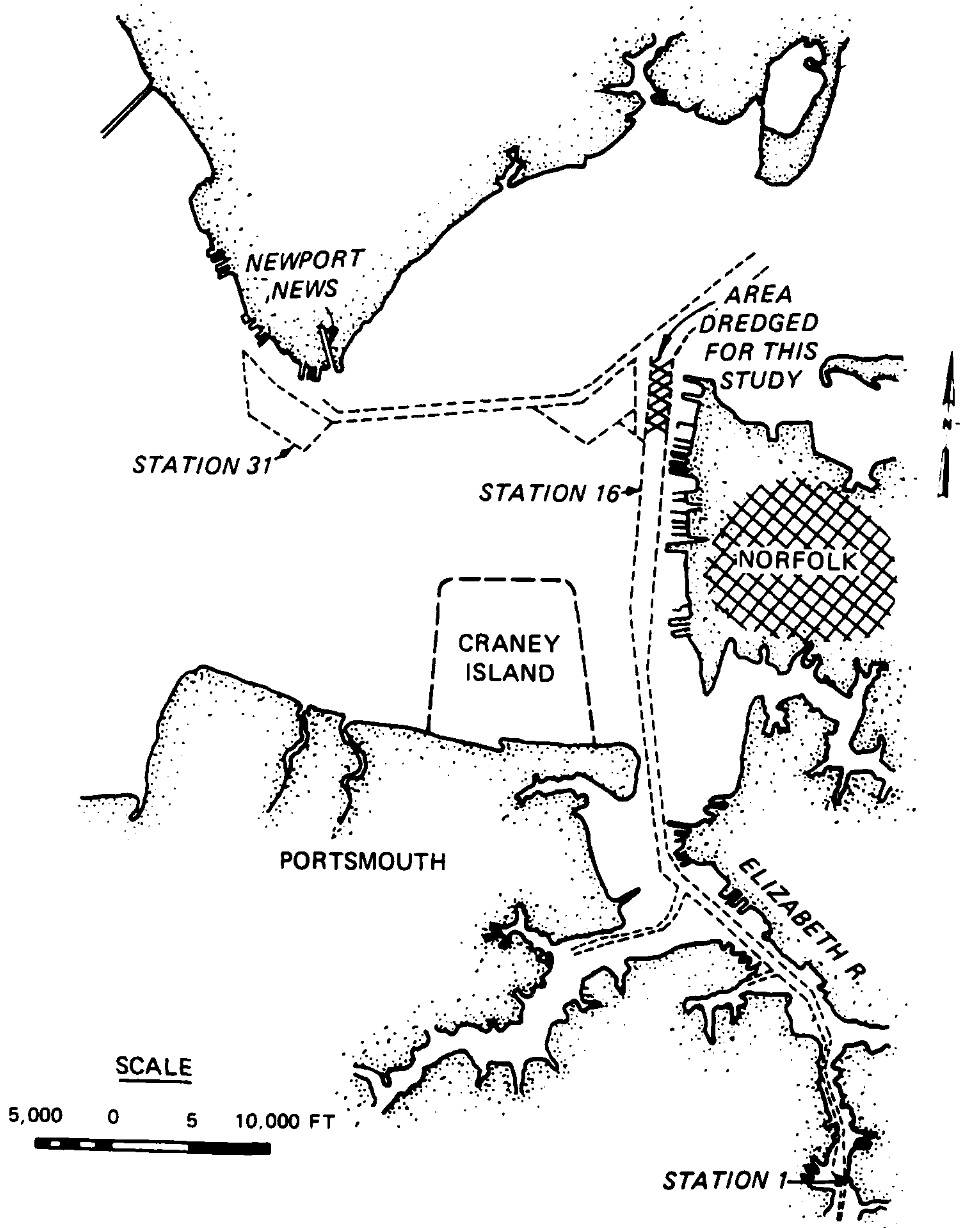


Figure 7. Norfolk Harbor, Virginia, showing location of channels, areas dredged, and Craney Island Disposal Area (Palermo, Shields, and Hayes 1981)

Program. Zone settling and compression tests were run, and a preliminary containment area design was furnished to the Mobile District.

Saginaw Harbor

62. Saginaw Harbor is located near Saginaw, Michigan, on an embayment of Lake Huron. Flocculent settling tests were performed on this freshwater sediment which was to be placed in the Middle Ground Island Disposal Area.

Savannah Harbor

63. The Savannah Harbor, Georgia, complex is unique with respect to the method and management of dredging and disposal operations. A layout of the project area is shown in Figure 8. Channels along the Savannah River have been progressively deepened to 38 ft, and shoaling was concentrated in reaches adjacent to the city of Savannah. A tide gate control structure was put into operation in 1977, creating a sediment basin or trap to concentrate shoaling in the Back River channel, thereby reducing shoaling in the navigation channel and reducing dredging costs. Approximately 7,000,000 yd^3 of material are removed annually from the project area.

64. Dredging in the Savannah Harbor is accomplished using hydraulic pipeline dredges, and the sediments are deposited directly into several large confined disposal sites adjacent to the Back River. These sites are well-managed disposal areas which provide good sedimentation. An intensive post-disposal management program to extend site life through dewatering and consolidation of the sediments after placement has also been implemented by the Savannah District (US Army Engineer District, Savannah 1982). Disposal Area 12, a 900-acre site located adjacent to the Back River, was used as a field evaluation site for verification of settling column data (Palermo 1984). (See Figure 8.)

65. Sediment samples were collected from Savannah Harbor in 1981 and in 1982. The 1981 samples were subjected to zone and compression settling tests. In August, 1982, a diving team collected sediment samples from the Back River. These samples were used for conducting flocculent settling tests above a zone settling interface. During 9-12 August, 1982, a field evaluation was conducted at Disposal Area 12. (See Figure 8.) The field evaluation included influent and effluent suspended solids concentration determinations and determination of retention time. A third sediment sample collected in 1983 was subjected to flocculent settling and compression tests.

Yazoo River

66. The Yazoo River dredging project, located near Belzoni, Mississippi, was evaluated by Montgomery (1978). The purpose of dredging at this

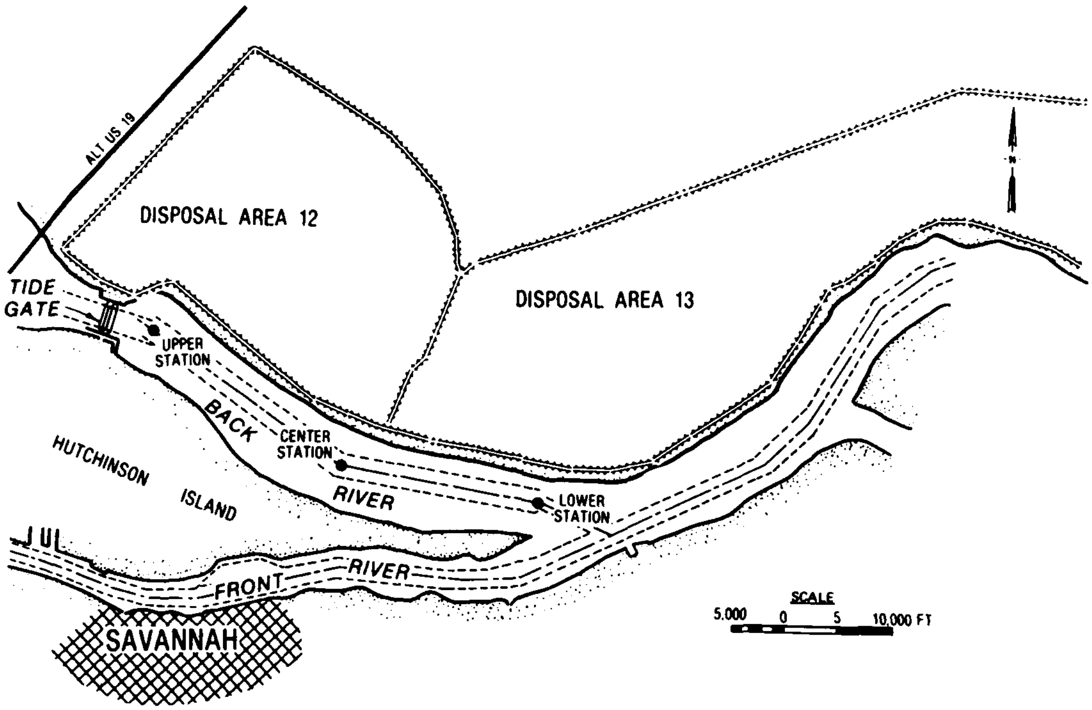


Figure 8. Savannah Harbor, Georgia, showing channels, sediment basin, and Disposal Area No. 12 (Palermo 1984)

site was to provide additional flood control by deepening and widening the Yazoo River, in contrast to the more common maintenance dredging projects. Sediment and water samples were collected and subjected to a flocculent settling test. This is the only flocculent settling test considered in this study where samples were collected from the settling column in the absence of a zone settling interface. A field investigation was conducted for this site in 1977. The disposal area consisted of an upper (450- by 1,800-ft) basin and a smaller lower basin. The field investigation determined influent and effluent suspended solids concentrations and suspended solids concentrations versus depth at the stations within the disposal area. Dye tests were performed to determine retention time. These data were used to verify the applicability of the flocculent settling test at a freshwater site. Additional flocculent settling tests were conducted in 1979 and 1980 for Yazoo River sediment samples.

Yellow Creek

67. Limited field sampling was conducted at the Yellow Creek, Mississippi, disposal area in the Nashville District. The disposal area is

located in a freshwater area at the Yellow Creek Embayment of Pickwick Reservoir on the Tennessee River, near Burnsville, Mississippi. The area is used for the disposal of sediments from maintenance dredging on the Tennessee-Tombigbee Waterway. The purpose of the sampling at Yellow Creek was to obtain a typical sample of freshwater material which would be expected to exhibit flocculent settling properties. A sample of material was taken directly from the disposal area immediately in front of the primary weir box. This sample was subjected to a flocculent settling test in the laboratory with samples withdrawn above the zone settling interface.

Sediment Characterization

68. Sediment samples collected for settling tests to facilitate containment area design should be routinely characterized, from an engineering standpoint, by the following tests:

- a. Atterberg limits.
- b. Grain size analysis.
- c. Salinity.
- d. Specific gravity.
- e. In situ water content.

Atterberg limits and grain size analyses will allow classification of the sediment according to the Unified Soil Classification System (USCS) and will provide a general indication of settling properties and how the material will behave in the containment area. The salinity of the sediment or the site water will predict the probability of zone settling behavior. Specific gravity and in situ water content are parameters needed for input to the design equations used for sizing the containment area. For samples classified visually as organic sediments, the organic content should be determined. If the organic solids content is greater than 10 percent, storage and preservation of the sample becomes much more critical because of potential biodegradation of the sample. Figure 9 is a flowchart of the testing program recommended for sediment samples. This flowchart was developed as a result of the experience gained in testing the sediments described in this report. Soil test procedures are in accordance with Engineer Manual (EM) 1110-2-1906 (Office, Chief of Engineers 1970). Settling test procedures are provided in Appendix A and

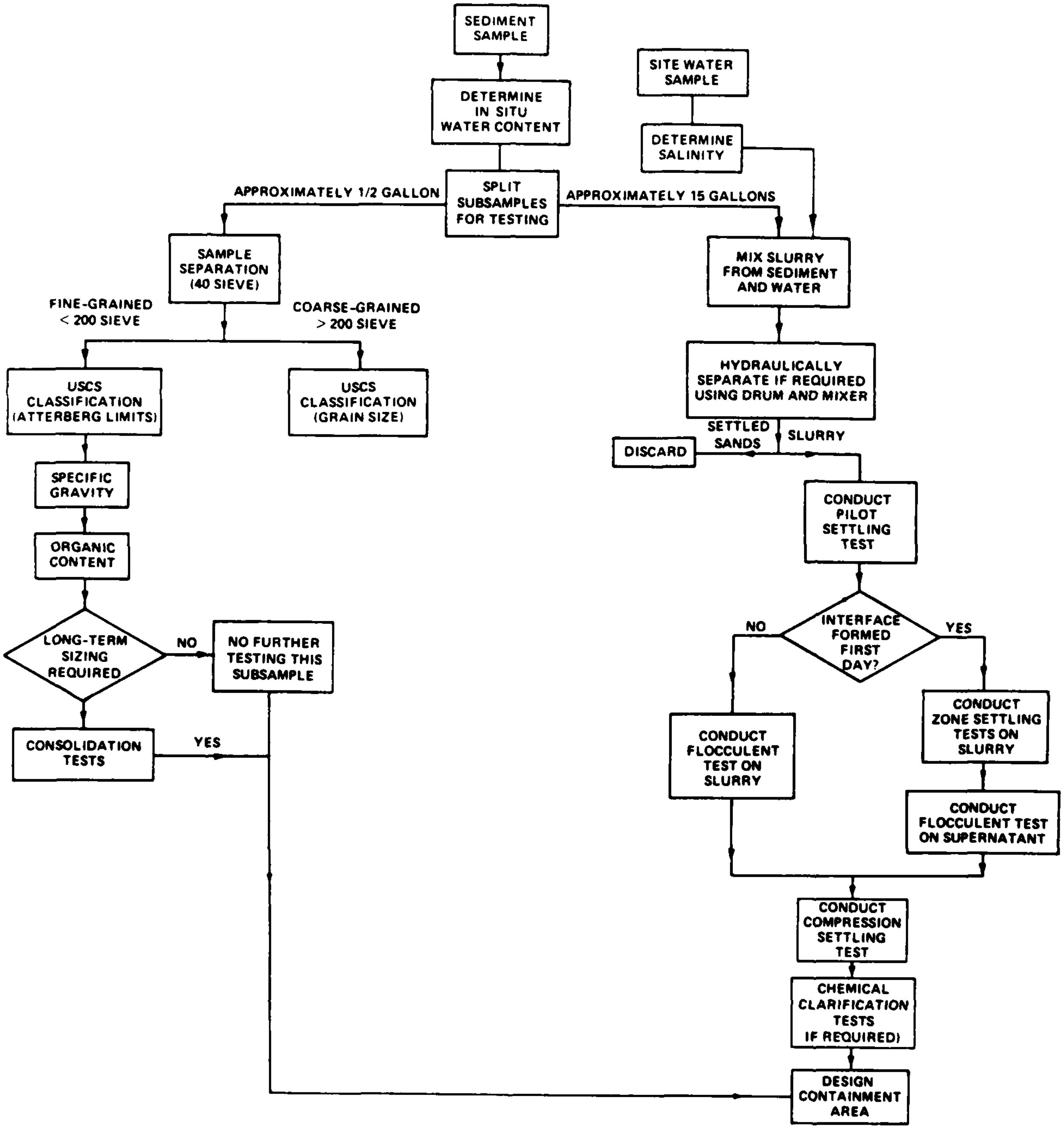


Figure 9. Flowchart depicting laboratory testing program for sediment samples (US Army Engineer Waterways Experiment Station 1985)

are included in a draft EM entitled "Confined Dredged Material Disposal" (US Army Engineer Waterways Experiment Station 1985).

69. Sediment samples discussed in this report were tested in general accordance with the procedure indicated in Figure 9. Results of the engineering characterization tests are shown in Table 2. Only a few samples were actually analyzed for organic solids content, and data for some other parameters were not found for some of the sediments.

70. USCS classification and Atterberg limits were available for most of the sediments. A plasticity chart, Figure 10, shows the relationships of plasticity indices to liquid limits for the sediments tested. Figure 10 shows that the settling studies discussed in this report represent a wide range of plasticity. The most predominant type of sediment was highly plastic clay (CH). The only sediments plotting below the A line were Irondequoit Bay (MH) and Black Rock (OH) sediments. Sediments classified as clays of low plasticity were Ashtabula Harbor, Indiana Harbor (1979*), and Yazoo River (1978*) sediments. Specific gravity of the sediments ranged from 2.44 to 2.71. Table 2 reports the percentage sand for samples where a grain size analysis was performed. The sand fraction ranged from less than 3 percent to 82 percent. Most of the sediment samples from harbor maintenance dredging projects would be expected to be predominantly fine-grained particles. The Gallipolis Lock sample was a new-location project, in which the material being excavated by dredging was primarily sandy material.

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* Date of sample collection.

Table 2

Engineering Characterization of Sediment

Site	Date	USCS Classification	Liquid Limit %	Plastic Limit %	Plasticity Index %	Organic Content %	Specific Gravity	Salinity ppt	Sand %
Ashtabula	1984	CL	44	25	19		2.7	<1.0	21
Black Rock	1982	OH	113	50	63	12.7	2.44	24.4	28
Charleston	1981	CH	152	51	101		2.59	20.0	
Fowl River	1977	CH	105	31	74	8.0	2.71	11.5	
Gallipolis Lock	1983							<1.0	82
Hart-Miller Island	1984							7.5	
Indiana Harbor	1979	CL	43	23	20	18	2.54	<1.0	48
Indiana Harbor	1984							<1.0	
Irondequoit Bay	1981	MH	86	47	39		2.70	<1.0	27
Kings Bay	1983	CH	170	152	18			24.0	<6
Little Lake	1981	CH	52	17	35			12.5	30
Mobile	1978	CH	82	28	54	7.4	2.68	17.0	
Mobile (Sta 28)	1983	CH	113	34	79			14.0	<5
Mobile (Comp.)	1983	CH						15.0	
Norfolk (1B)	1980	CH	166	49	117				
Norfolk (16B)	1980	CH	113	38	81				
Norfolk (31B)	1980	CH	121	37	84				
Norfolk (55 ft)	1981	CH	82	30	52			20.0	
Norfolk	1983	CH	110	31	79			16.2	<5
Port Bienville	1981	CH	57	16	41			13.0	
Saginaw	1983								
Savannah	1981	CH	170	155	15		2.67	25.0	
Savannah	1983	CH	170	52	118			<1.0	
Yazoo River	1978	CL	38	20	18		2.67		
Yazoo River	1979								<3
Yazoo River	1980								
Yellow Creek	1982	CH	88	33	55				

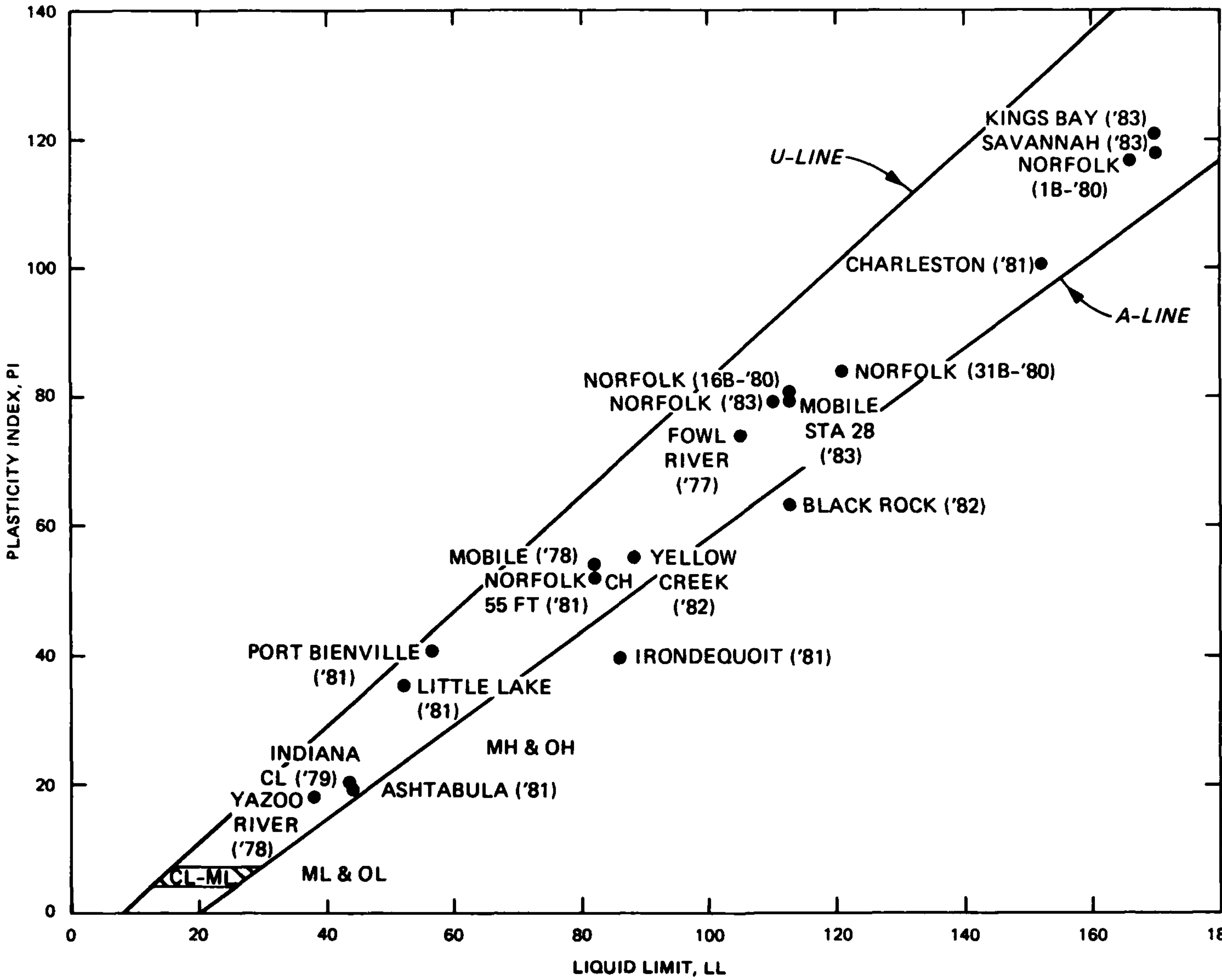


Figure 10. Plasticity chart for tested sediment samples

Part III: COLUMN SETTLING TESTS AND DATA ANALYSIS

Column Settling Test Procedures

71. This study considers all of the laboratory settling tests recommended for the design of dredged material containment areas. These tests are the zone settling test, the compression settling test, the freshwater flocculent settling test, and the supernatant flocculent settling test. All of these tests are performed in an 8-in.-diam, 6-ft-high Plexiglas cylinder. The procedure for selection of the appropriate settling tests to be conducted is illustrated in Figure 9. Detailed procedures for performing the settling tests are included in Appendix A.

72. Table 1 illustrates the types of tests performed on sediments for the 28 different sediment samples evaluated in this report. Most sediments were subjected to more than one type of settling test. Many of the sediments were tested primarily for specific research purposes and all of the data that would be required to design a containment area may not have been acquired on these sediments.

Data Analysis Procedures

73. The laboratory settling data were analyzed by the Automated Dredging and Disposal Alternatives Management System (ADDAMS). ADDAMS is a collection of computer programs useful in planning, designing, and operating dredging and dredged material disposal projects. ADDAMS helps solve many of the problems involving repetitive calculations which arise in typical dredging projects. Maintained on the Control Data Corporation (CDC) cybernet system, ADDAMS can be operated interactively and includes graphics features. A user's manual (Hayes et al. 1985) is being developed to instruct users in access to and step-by-step operation of the program.

Organization and capabilities of ADDAMS

74. ADDAMS currently consists of seven independent programs or modules, which are described below.

75. This study used the procedures and techniques provided by the sedimentation design module available in ADDAMS (SETT) to analyze laboratory settling data and to estimate design requirements for the retention of suspended

Four-Character Name Of ADDAMS Module	Description
DYEC	Hydraulic efficiency by dye tracer
TRAN	Transportation of dredge material data
DISP	Dredged material disposal site data
DREG	Dredging site data
DDMM	Dredged material management model
SETT	Sedimentation design
CONS	Long-term consolidation

solids and the provision of sufficient volume for initial storage of sediments. The calculations used by SETT are based on the procedures described in Appendixes A and B. An example of SETT input and output for Hart-Miller Island is provided in Appendix C.

76. The SETT input routine has four divisions to simplify data entry procedures, as follows:

COMP	Compression settling test analysis
ZONE	Zone settling test analysis
FLOC	Flocculent settling test analysis
PROJ	Project data entry

77. The SETT input routine generated the plots of settling test results shown in Appendix D.* Graphs generated by the input routine are the compression, the zone settling, the solids loading, the flocculent, and the percent removal or total suspended solids curves as described in Appendixes A and B. The SETT output routine will plot all graphs available in the input and provide a listing of site characteristics and design results. The total suspended solid versus retention time graphs in Appendix D were generated by the output routine. The Tektronics 4114A terminal plotter was used to enter the data and plot the curves.

* Reproduced on microfiche and enclosed in a pocket attached to the inside back cover.

78. Curves developed by the SETT module are based on least squares curve-fitting analysis. Mathematical curve fits do not always generate the same type of curve that would be drawn by hand using engineering judgment. ADDAMS provides the capability for the designer to change the coefficients of the curves and to delete outlying points in order to yield a curve more suitable for the purposes of the designer. However, for this study, coefficients developed by the least squares technique were not adjusted. Outlying or questionable data points were eliminated from the analysis to produce curves more representative of the actual dredged material settling behavior.

Column Settling Test Results

Zone settling tests

79. Zone settling tests require the observation of the elevation of an interface in an 8-in.-diam column over time, as described in Appendix A. The zone settling velocity is dependent on the initial concentration of the slurry. The procedure is to run a series of zone settling tests for the range of initial solids concentrations that could be encountered in the field. An example of a test series for the Little Lake sediment is illustrated in Figure 11. Eight tests were run at initial solids concentrations ranging from 46.6 to 197.7 g/ℓ. Zone settling velocity is taken as the slope of the linear portion of each curve. As initial solids concentration increases, the absolute value of the zone settling velocity decreases. Table 3 shows zone settling velocities for Little Lake ranged from 0.51 to 0.12 ft/hr. When the settling curve departs from a linear relationship, compression settling begins.

80. The relationship between zone settling velocities from the series of tests and the corresponding initial solids concentrations is an exponential curve of the form

$$v_s = ae^{bC} \qquad (1)$$

where v_s is the zone settling velocity (L/T), C is the initial solids concentration (M/L^3), and a and b are the intercept and slope, respectively, of a v_s versus C semilog plot. These plots as generated by ADDAMS are shown for all of the sediments subjected to the zone settling test in

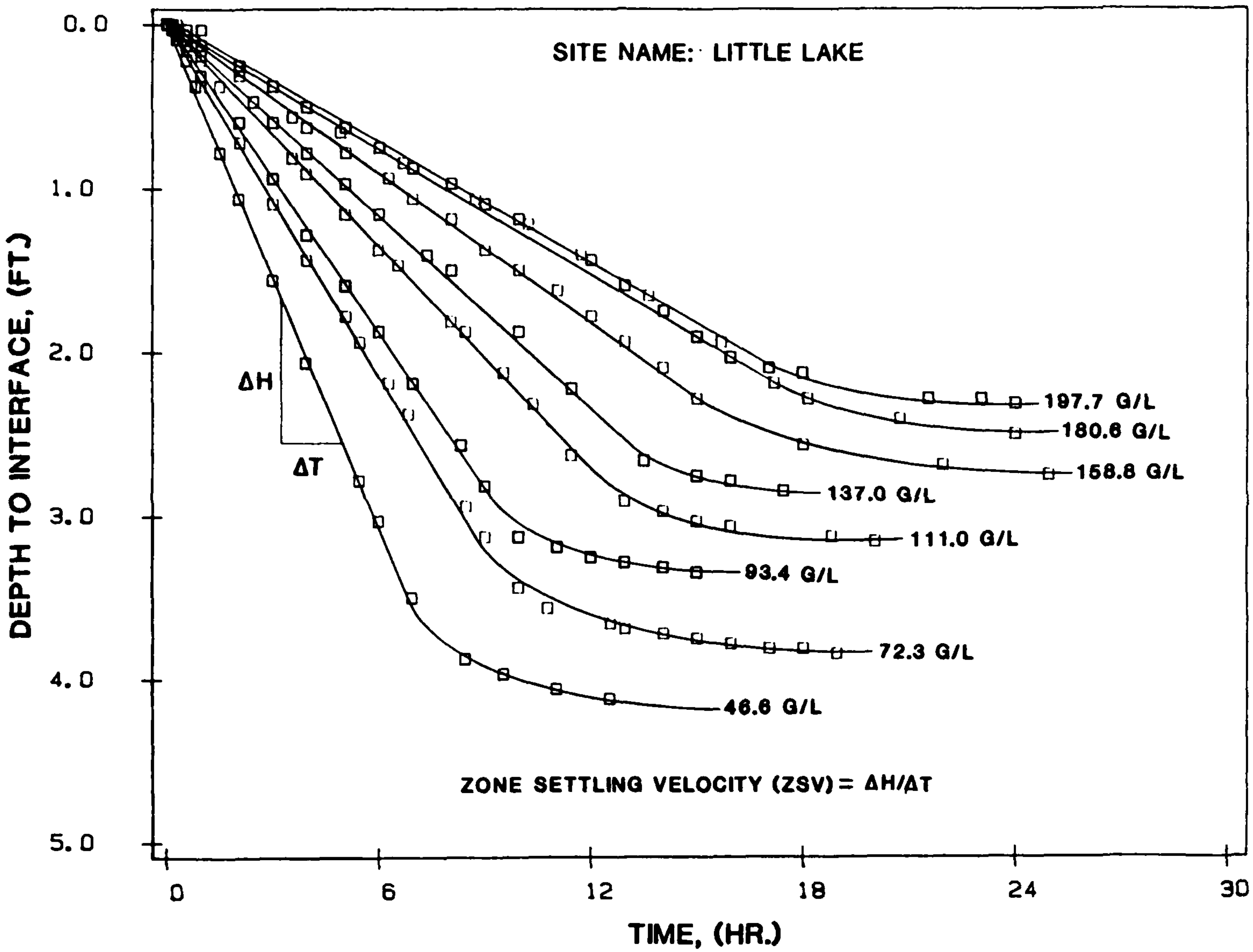


Figure 11. Zone settling test curves for Little Lake

Table 3

Zone Settling Velocities for Little Lake

Concentration g/ℓ	Zone Settling Velocity ft/hr
46.6	0.51
72.3	0.35
93.4	0.32
111.0	0.23
137.0	0.20
158.8	0.14
180.6	0.12
197.7	0.12

Appendix D. Figure 12 illustrates all of the zone settling test results plotted on one graph for comparison among sediments. Details for these curves are given in Table 4. Zone settling velocities shown in Table 4 for 150 g/ℓ solids range from 0.024 to 0.85 ft/hr. The greatest velocity (0.85 ft/hr) was for Irondequoit Bay. Excluding Irondequoit Bay from the data set results in a maximum of 0.27 ft/hr for Mobile Harbor. The indices of determination (r^2) from Table 4, which indicate the goodness of fit for the curves, range from 0.41 to 0.98. Eight of the thirteen curves had values of r^2 greater than or equal to 0.90. Curves with lower values of r^2 usually had one or two points away from the linear trend that caused the calculated value of r^2 to be lower. Since many of these tests were performed several years ago, it is difficult to determine reasons to justify deleting what appear to be invalid data points, particularly where there are only five or six points.

81. To illustrate the range of zone settling velocities and concentrations observed for all of the sediments tested, data generated from the regression curves for representative test concentrations of 100, 150, and 200 g/ℓ are plotted in Figure 13. This figure shows that settling data from the zone settling test varies among different types of sediment.

82. For design purposes, zone settling data are replotted in the form of solids loading (M/L^3-T) versus concentration (M/L^3). ADDAMS generates this curve based on the best fit curve of $\ln v_s$ versus C. Appendix D includes

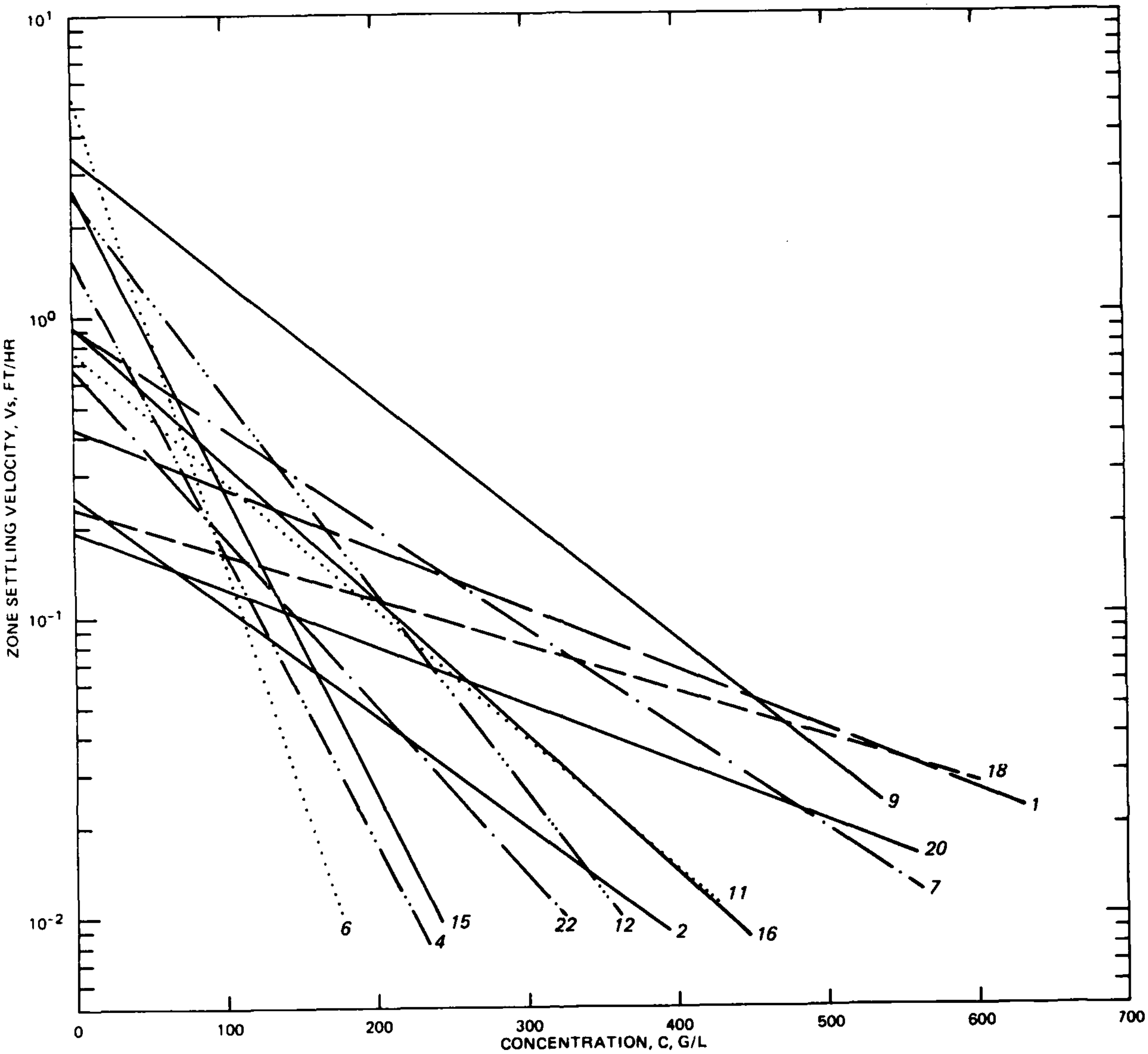


Figure 12. Zone settling velocity versus concentration curves for 13 sites (See Table 4 for descriptions of curves by site number)

solids loading curves for all the zone settling tests evaluated during this study.

Compression settling tests

83. The compression settling test was performed on more sediment samples than zone settling or flocculent settling tests were. Design of a containment area requires compression settling test data to calculate the initial volume for dredged material storage regardless of the other types of settling which may be occurring. If zone settling is occurring, compression test data

Table 4

Zone Settling Test Curve Coefficients and Comparison of Zone Settling Velocities (ZSV) Among Sites

Site No.	Site Name (Year Tested)	ZSV vs. Concentration Intercept	Slope	r^2	ZSV, ft/hr Solids Concentration 100 g/ℓ	150 g/ℓ	200 g/ℓ
1	Ashtabula (1981)	0.42	-0.0063	0.85	0.22	0.16	0.12
2	Black Rock (1982)	0.25	-0.0085	0.48	0.11	0.070	0.046
4	Fowl River (1977)	1.58	-0.023	0.82	0.16	0.050	0.016
6	Hart Miller (1984)	5.39	-0.036	0.97	0.15	0.024	0.0040
7	Indiana Harbor (1979)	0.92	-0.0088	0.96	0.38	0.25	0.16
9	Irondequoit Bay (1981)	3.31	-0.0091	0.92	1.33	0.85	0.54
11	Little Lake (1981)	0.76	-0.0099	0.98	0.28	0.17	0.10
12	Mobile Harbor (1978)	2.52	-0.015	0.96	0.56	0.27	0.13
15	Norfolk Harbor (1B-1980)	2.66	-0.025	0.90	0.22	0.063	0.018
16	Norfolk Harbor (16B-1980)	0.94	-0.011	0.90	0.31	0.18	0.10
18	Norfolk Harbor (55/-1981)	0.23	-0.0035	0.41	0.16	0.14	0.11
20	Port Bienville (1981)	0.19	-0.0044	0.48	0.12	0.098	0.079
22	Savannah Harbor (1981)	0.67	-0.013	0.96	0.18	0.095	0.050

are also required to select the minimum surface area for the containment area. Detailed design procedures are given in Appendix B.

84. The compression settling test requires observation of the fall of a solids-liquid interface in a settling column over a 15-day time period, as described in Appendix A. The compression test is performed with the slurry at the expected initial solids concentration entering the containment area. Generally, a value of 150 g/ℓ is used for the solids concentration where no other data are available. Changes in interface height are converted to average

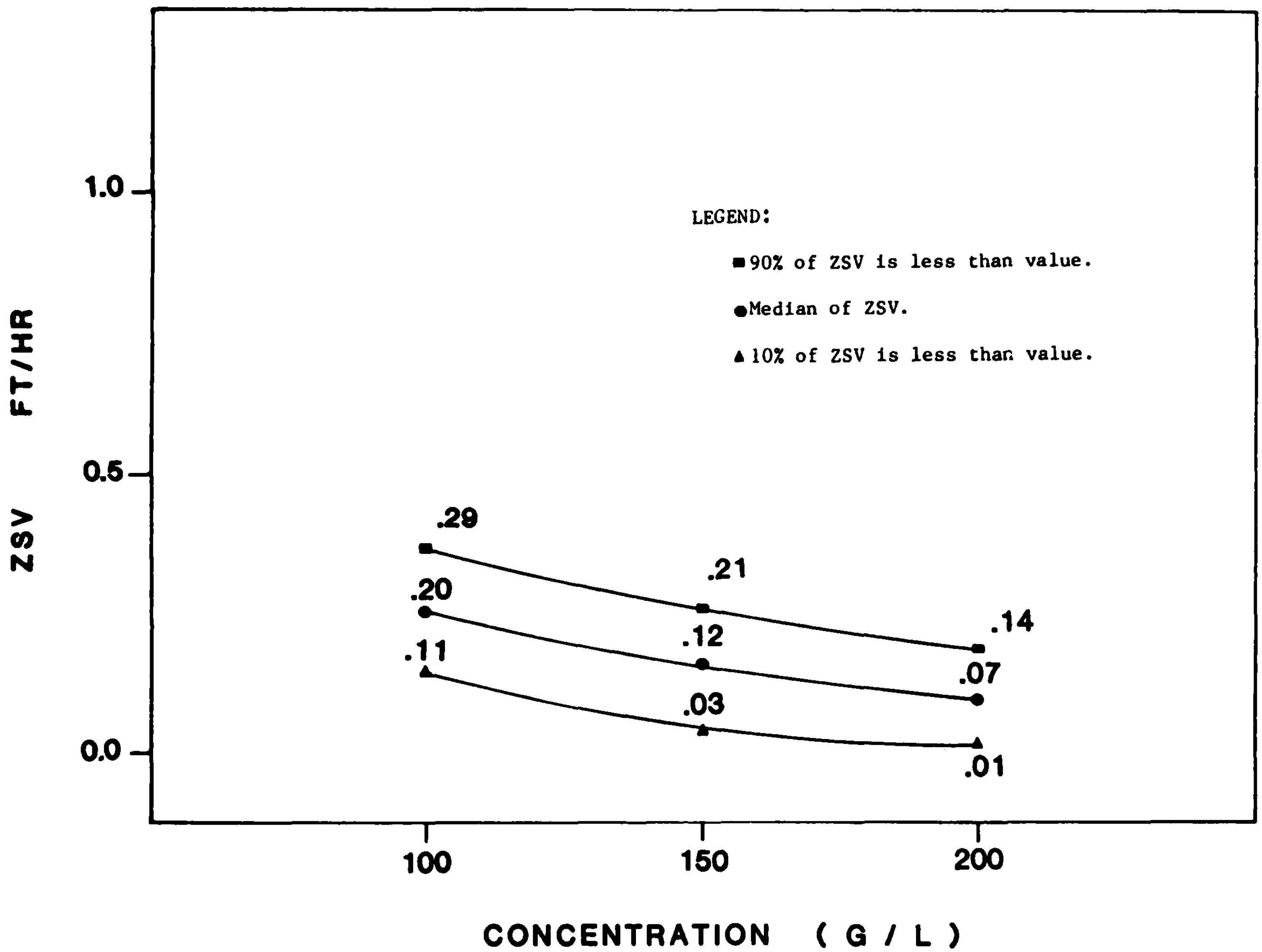


Figure 13. Variability of zone settling data

solids concentrations below the interface. These concentrations, when plotted against time on log-log paper, generally yield a straight line.

85. Compression settling test plots for all of the sediments evaluated are presented in Appendix D. Figure 14 and Table 5 are presented to compare compression test results among the various sediment samples. The log-log plot yields a line described by the equation

$$C = aT^b \tag{2}$$

where C is the average solids concentration, a and b are the constants for the equation, and T is time. Slopes ranged from 0.052 to 0.213. The r^2 value was greater than 0.95 for most of the plots, indicating a good fit to the equation. Table 5 includes a column for the average solids concentration below the interface using $T = 15$ days in the regression equation. These values ranged from 150 to 495 g/ℓ. Sites with an average solids concentration of less than 150 g/ℓ after 1 day of settling obviously had an initial solids concentration of less than 150 g/ℓ, the commonly used value.

Flocculent settling tests

86. The initial settling test research by Montgomery (1978) showed that a freshwater sediment exhibited flocculent settling characteristics. Palermo (1984) showed that flocculent settling also occurred in the supernatant above a zone settling interface and that the flocculent settling test could be used to predict the level of effluent suspended solids in a containment area in which zone settling was occurring. A number of flocculent settling tests have been performed on dredged material since 1978. The majority of these were supernatant flocculent settling tests, i.e., tests on solids above the zone settling interface. Of the sediment sampling sites listed in Table 1, only Gallipolis Lock and Yazoo River sediments (1978) were subjected to the standard flocculent settling test. The other sites, which include freshwater as well as saltwater sediments, exhibited zone settling, and the flocculent settling test procedure (Appendix A) was applied to the solids in the supernatant above the liquid-solids interface.

87. Flocculent settling test results produced by ADDAMS for each sediment tested are presented in Appendix D. Fitting curves to flocculent settling test data for dredged material generally requires more engineering

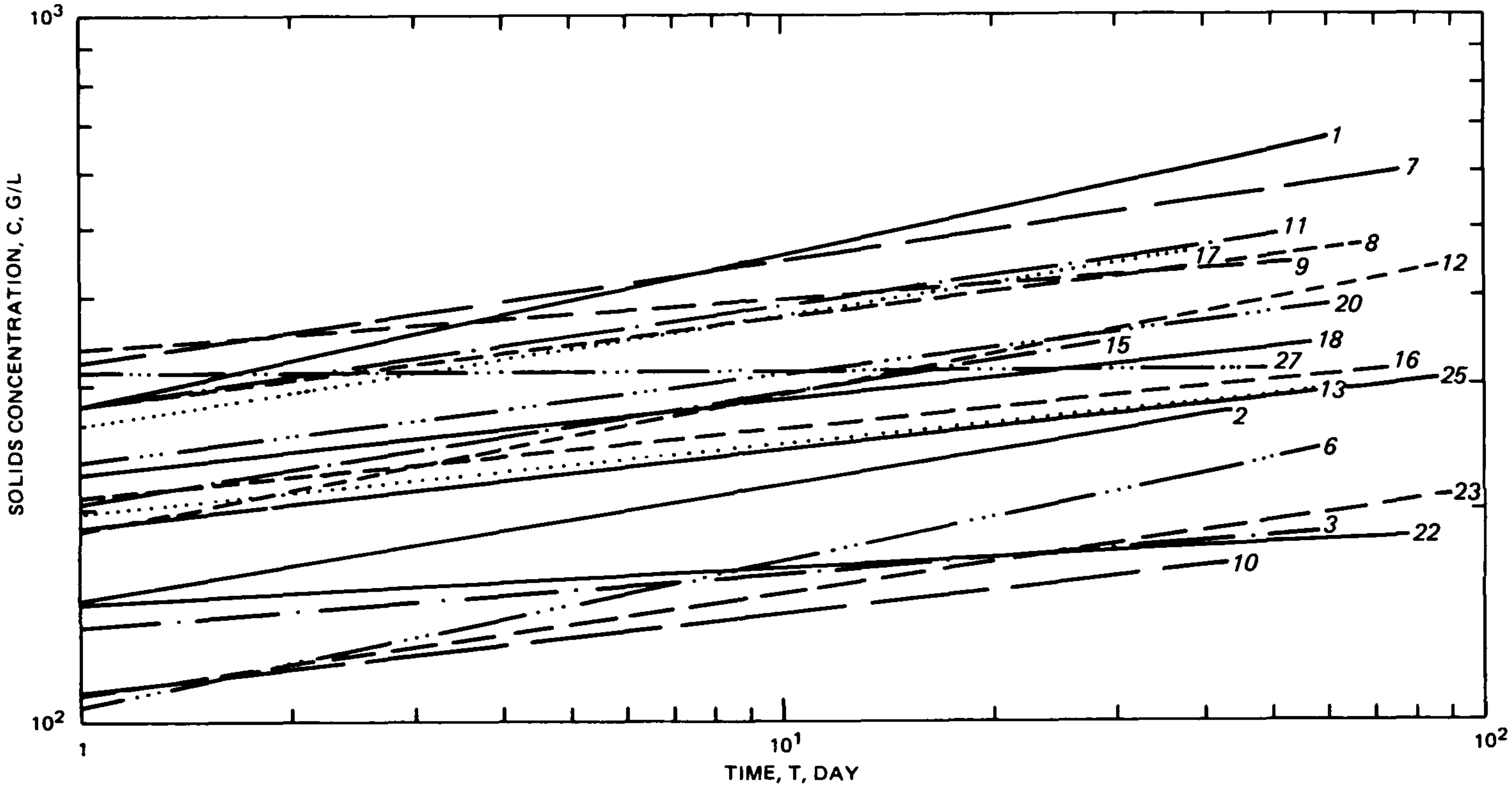


Figure 14. Compression settling curves for 20 sediment samples. (See Table 5 for description of curves by number)

Table 5

Compression Test Results

Site* No.	Site Name (Year Tested)	Concentration vs Time ($C=aT^b$) a	b	r^2	Solids Concentration at 15 days, g/ℓ
1	Ashtabula Harbor (1984)	278.0	0.213	1.00	495
2	Black Rock (1982)	149.1	0.163	1.00	239
3	Charleston (1981)	136.5	0.077	0.978	168
6	Hart Miller (1984)	105.5	0.208	0.994	185
7	Indiana Harbor (1979)	322.0	0.057	0.987	376
8	Indiana (1984)	278.0	0.126	0.996	391
9	Irondequoit Bay (1981)	337.2	0.073	0.932	411
10	Kings Bay (1983)	110.3	0.113	0.969	150
11	Little Lake (1981)	278.9	0.141	0.999	409
12	Mobile Harbor (1978)	186.6	0.193	0.975	315
13	Mobile Sta 28 (1983)	189.0	0.109	0.999	254
14	Norfolk (1B-1980)	204.5	0.161	0.998	316
15	Norfolk (16B-1980)	207.1	0.100	0.980	272
16	Norfolk (31B-1980)	262.7	0.159	0.998	404
17	Norfolk 55' (1981)	224.9	0.106	0.999	300
20	Port Bienville (1981)	233.5	0.127	0.919	329
22	Savannah Harbor (1981)	146.4	0.052	0.956	168
23	Savannah (1982)	109.2	0.144	0.977	161
25	Yazoo River (1978)	199.6	0.102	0.910	263
27	Yazoo River (1980)	314.1	0.065	0.988	375

* Site number corresponds to curve number in Figure 14.

judgment than fitting curves to data from zone settling and compression tests. Review of the flocculent settling test curves in Appendix D shows that sometimes the data points do not produce neat, smooth curves. In some cases, suspended solids concentration increases with time at a given depth, and sometimes it decreases with depth at a given time. Possible explanations for these data are precipitation of iron and other metals as a result of exposure to oxidizing conditions, attraction and accumulation of solids near the column wall and the point of sample extraction, or biological activity in the settled solids, thereby releasing gases and resuspending solids. The first of these explanations has been observed in the laboratory and is the more likely cause of perturbations in the data, particularly after settling times exceeding 24 hr.

88. The results of the flocculent settling test for the Yazoo River freshwater sediments that did not produce an interface are illustrated in Figure 15. This graph compares the effect of retention time on effluent suspended solids at ponding depths of 1, 2, and 3 ft. It shows that increasing the retention time beyond 30 hr provides little additional decrease in effluent suspended solids concentration. To achieve the stringent effluent limits imposed by regulatory agencies for sediments of this nature will require the addition of chemical coagulants to promote release of bound water and additional increases in solids concentration.

89. Table 6 compares the retention times necessary to achieve five specified effluent suspended solids concentrations at the 2-ft depth for all of the supernatant flocculent settling tests. Several sediments were tested at different initial solids concentrations. Palermo (1984) plotted results for three initial concentrations of the Mobile Harbor composite sediment (1983). This plot (Figure 16) shows that greater initial solids concentrations require longer detention times to achieve the same effluent quality. Because of this effect, the initial solids concentration for the test should be as close as possible to the anticipated field influent solids concentration (Palermo 1984).

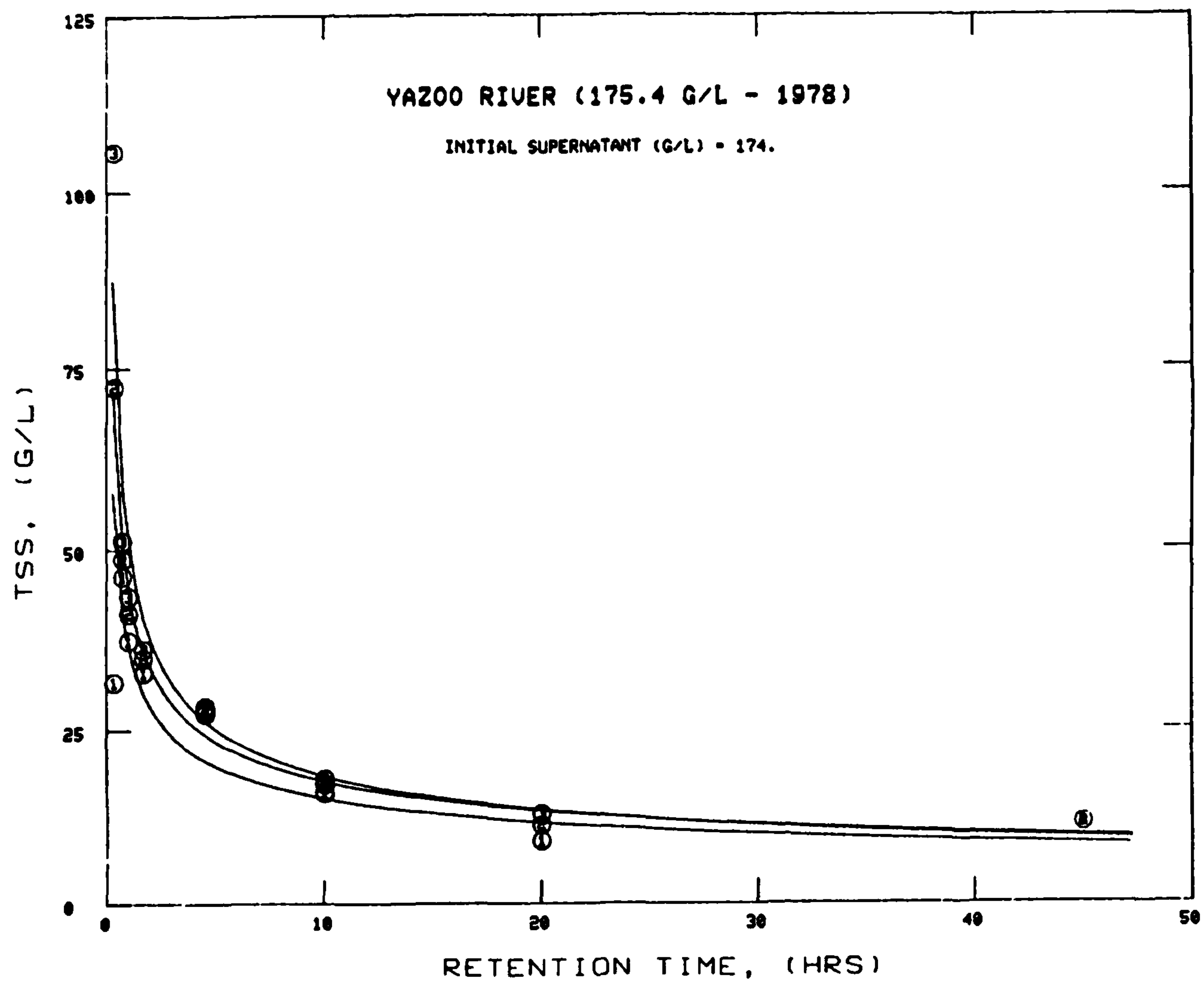


Figure 15. Effect of retention time on effluent suspended solids for Yazoo River sediment

Table 6

Retention Times (hr) Required To Achieve Effluent Suspended Solids Concentrations at 2-ft Ponding Depth

Sediment Location (Year Tested)	Initial Slurry Concentration (g/ℓ)	Time (hr) Required to Achieve Stated Concentration				
		25 mg/ℓ	50 mg/ℓ	100 mg/ℓ	200 mg/ℓ	400 mg/ℓ
Ashtabula (1984)	124	46	38	32	27	22
Ashtabula (1984)	80	22	18	14	12	<10
Black Rock (1982)	57	>50	28	<10	<10	<10
Black Rock (1982)	105	>50	>50	30	<25	<25
Gallipolis (1983)	32	<5	<5	<5	<5	<5
Hart Miller (1984)	54	>150	44	16	4	2
Hart Miller (1984)	98	37	26	<22	<22	<22
Hart Miller (1984)	152	77	52	<45	<45	<45
Indiana Harbor (1979)	63	>6	>6	3	2	2
Indiana Harbor (1984)	100	>50	>50	>50	>50	>50
Irondequoit (1981)	148	>30	>30	22	5	<4
Kings Bay (1983)	96	120	82	<80	<80	<80
Kings Bay (1983)	132	28	18	11	7	<5
Mobile Sta. 28 (1983)	99	17.4	9	5	<5	<5
Mobile Comp (1983)	58	21	11	6	<6	<6
Mobile Comp (1983)	108	25	12	<9	<9	<9
Mobile Comp (1983)	155	26	10	<10	<10	<10
Norfolk (1983)	122	20	4	<4	<4	<4
Saginaw (1983)	70	>100	>100	86	40	20
Savannah (1982)	95	44	<44	<43	<43	<43
Savannah (1983)	99	>400	151	48	<80	<80
Yazoo (1978)	175	>50	>50	>50	>50	>50
Yazoo (1979)	156	>100	>100	>100	83	64
Yazoo (1980)	111	>25	>25	>25	>25	>25
Yellow Creek (1982)	33	>400	>400	>400	>400	>400
Yellow Creek (1982)	148	>400	>400	>400	>400	>400
Yellow Creek (1982)	170	>500	>500	>500	>500	>500

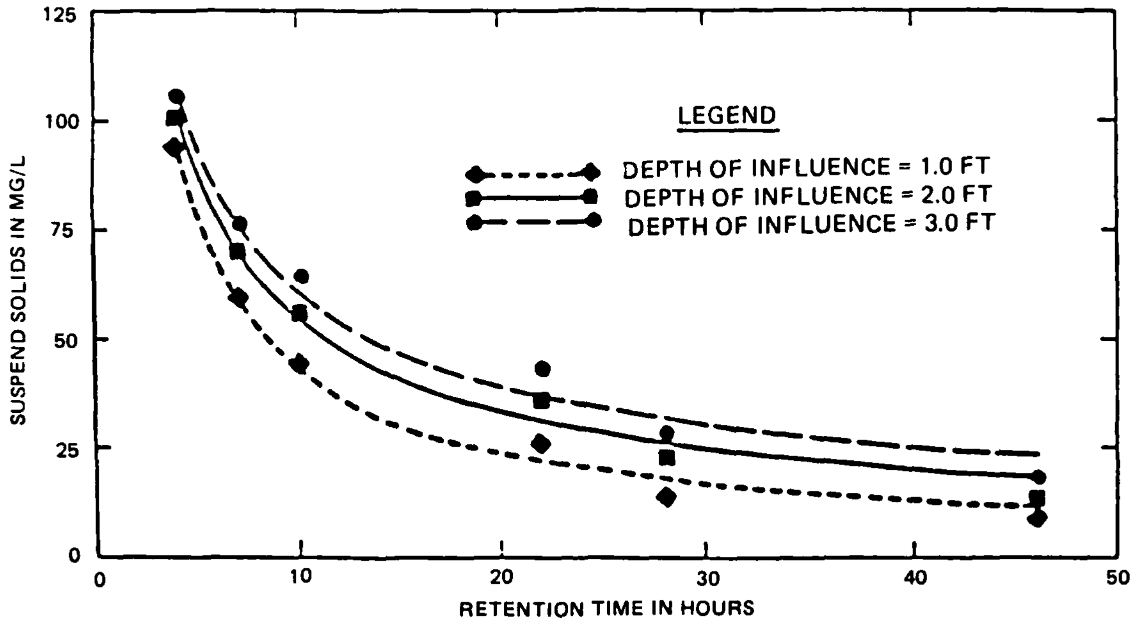


Figure 16. Effect of initial test concentration on effluent suspended solids predicted by the supernatant flocculent settling test

PART IV: FIELD VERIFICATION OF FLOCCULENT AND ZONE SETTLING TESTS

Flocculent Settling Test Verification

Field testing sites

90. Effluent suspended solids data from field tests for comparison to laboratory column testing data are available for the following sites:

- a. Black Rock Harbor (1982).
- b. Kings Bay (1983).
- c. Mobile Harbor - Sta 28 (1983)..
- d. Norfolk Harbor (1983).
- e. Savannah Harbor (1983).
- f. Yazoo River (1978).

Except for the Yazoo River Site, all of the sites are saltwater environments with sediments which exhibit zone settling behavior. However, flocculent settling tests were performed on the supernatants concurrently with zone settling tests to predict effluent suspended solids concentrations as a function of retention times. The Yazoo River sediment is a freshwater sediment that did not develop a solid-liquid interface, and it can be described by the standard flocculent settling test.

91. During field studies conducted at these sites, the mean effluent suspended solids concentrations discharged from the containment area, the mean retention times (from using dye studies), the ponded area, and the ponded depth were determined. Complete descriptions of the field evaluations have been previously reported by Montgomery (1978) and Palermo (1984). The results of these flocculent settling tests are compared to measured concentrations from the field in this section.

Laboratory studies

92. Flocculent settling tests were performed on sediments from these sites as described in Part III and Appendix A of this report. The initial slurry concentrations used in the laboratory were prepared to approximately equal the anticipated field mean influent suspended solids concentrations. Table 7 describes the laboratory test suspended solids concentrations and field influent suspended solids concentrations and refers to the appropriate ADDAMS-generated curves in Appendix D.

Table 7

Laboratory and Field Slurry Concentrations and Reference to Laboratory Curves in Appendix D

Site (Year Tested)	Slurry Concentration (g/ℓ)		Laboratory Settling Curves	
	Laboratory	Mean Field	Concentration Profile	Effluent Suspended Solids versus Retention Time
Black Rock (1982)	57	60.7	D11	D12
Kings Bay (1983)	96	150	D43	D44
Mobile Sta 28 (1983)	99	87.6	D54	D55
Norfolk (1983)	122	122	D72	D73
Savannah (1983)	99	107	D86	D87
Yazoo River (1978)	175	109	D89	D90

ADDAMS design

93. The project module (PROJ) for the ADDAMS computer-aided design system was used to calculate the effluent suspended solids concentrations based on laboratory settling tests. To do this, ADDAMS must be fed information about the project, depending on the type of output required. The program does not accept retention time as an input value, but calculates it based on flow rate, surface area ponded, average depth, and hydraulic efficiency. ADDAMS uses the calculated best-fit exponential curve of percent solids removal versus retention time to calculate effluent suspended solids concentrations for the project retention time. ADDAMS also provides as output a graph showing predicted effluent suspended solids concentrations as a function of retention time and average depth. This is a convenient method of demonstrating the additional quality benefits (in terms of lower effluent suspended solids concentrations) of increasing retention time. An example of project input data and program-generated output for the Kings Bay sediment is provided in Table 8. The corresponding curve for effluent suspended solids concentrations versus retention time is illustrated in Appendix D.

94. Predicted effluent suspended solids concentrations and measured field effluent concentrations for the six field verification sites are presented in Table 9. The ratio of predicted to measured concentrations ranges from 0.48 to 1.19.

Settling efficiency factors

95. The refined approach for prediction of effluent suspended solids concentrations described above assumes that the site is well designed and is operated so that effective sedimentation can occur, that the weir is of sufficient crest length, and that ponding conditions are such that resuspension of settled material is avoided. An acceptable design implies that adequate ponded surface area and storage volume are available for the zone settling process to concentrate the dredged material, if the zone settling process prevails for the entire slurry mass. However, the mean field effluent concentration for well-designed and well-operated sites would likely be higher than that indicated by quiescent laboratory tests. The data in Table 9 confirm this. Plots of means and standard deviations for field effluent suspended solids concentrations and values predicted using the column procedure described above are also shown in Figure 17. These data graphically show that the mean field effluent concentration is higher than the concentration

Table 8

ADDAMS Analysis of Kings Bay

Flocculent Settling Data

SUMMARY OF INPUT DATA

CHANNEL SEDIMENT VOLUME	(TCY) =	
DIKE CREST HEIGHT	(FEET) =	
EFFLUENT SOLIDS CONCENTRATION	(GPL) =	
TOTAL SURFACE AREA	(ACRE) =	380.00
DISCHARGE FLOW RATE	(CFS) =	27.00
DISCHARGE PIPE DIAMETER	(FEET) =	
DISCHARGE VELOCITY	(FPS) =	
PERCENT OF SURFACE AREA PONDED	(%) =	100.00
INFLUENT SOLIDS CONCENTRATION	(GPL) =	150.00
HYDRAULIC EFFICIENCY	(NONE) =	.44
PONDED WATER DEPTH	(FEET) =	1.00
INITIAL VOID RATIO	(NONE) =	
SPECIFIC GRAVITY	(NONE) =	2.70
COARSE-GRAINED FRACTION	(%) =	.00
EFFECTIVE DREDGING TIME	(%) =	100.00
OPERATING TIME PER DAY	(HPD) =	24.00
FREEBOARD HEIGHT	(FEET) =	

Analysis of Flocculent (Type 2) Settling Test

EFFLUENT SOLIDS CONCENTRATION (MG/L) = 46.14 <--- CALCULATED VALUE

PONDED SURFACE AREA(ACRES) = 380.00

VOLUMETRIC FLOW RATE(CFS) = 27.00

Table 9

Comparison of Predicted Effluent Suspended Solids Concentrations to Measured Field Concentrations

Site	Test Slurry Concentration g/ℓ	Approx. Ponded Area acres	Approx. Average Depth ft	Mean Field Retention Time, hr*	Mean Field Suspended Solids mg/ℓ	Column Suspended Solids mg/ℓ	Ratio, Lab to Field	Resuspension Factor**	Predicted Suspended Solids mg/ℓ	Ratio of Predicted SS to Field SS
Black Rock	57	<1	<1	8	173	91.4	0.53	2.0	182.8	1.06
Kings Bay	96	380	1	75	50	46.1	0.93	2.5	115.3	2.31
Mobile	99	40	1	12	40	28.2	0.70	2.0	56.4	1.41
Norfolk	122	600	>2	41	35	16.7	0.48	2.0	33.4	0.95
Savannah	99	153†	>2	53	75	88.8	1.19	1.5	133.2	1.78
Yazoo	175	37	1	48	8,050	5,460	0.68	2.0	10,920.0	1.36

* Field mean retention was determined by dye tracer with the exception of the Kings Bay Site. For this site, the mean retention time was estimated by applying a hydraulic efficiency factor of 2.25 to the estimated theoretical retention time.

** Resuspension factor selected from Appendix B.

† Total surface area ponded for the Savannah Site was approximately 400 acres. However, a majority of this area was involved in overland flow. A relatively sheltered area ponded to depths of 2 ft or greater was limited to approximately 50 acres immediately in front of the weir. The selected resuspension factor for this site corresponds to a ponded area less than 100 acres and ponded depth greater than 2 ft.

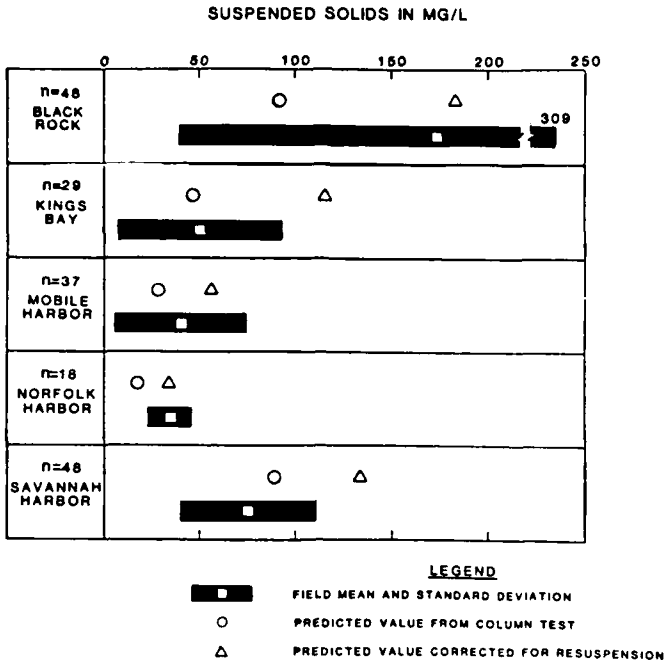


Figure 17. Means and standard deviations for field effluent suspended solids concentrations and predicted concentrations from column settling tests

predicted from column tests for five of the six comparisons. The predicted values of effluent suspended solids concentrations using the modified McLaughlin analysis could therefore be considered a minimum value which could be achieved in the field under the best possible conditions for settling (i.e., little flow-generated turbulence and little to no solids resuspension because of wind effects). The comparison of predicted concentrations from the column tests and measured mean field concentrations in Column 8 of Table 9 show that an adjustment for flow-generated turbulence and anticipated solids resuspension due to wind would be appropriate for most cases. Even though the available field data were limited, the range of ratios of field values to predicted values shown in Column 8 of Table 9 is a good indicator of appropriate factors for adjusting the predicted values for anticipated turbulence and solids resuspension.

96. A reasonable approach in selecting appropriate settling efficiency factors would be based on both anticipated ponded areas and anticipated average depths. The level of turbulence is related to flow velocities, which are inversely proportional to ponded surface area and average depth. However,

wind effects usually influence flow velocities in shallow confined disposal areas to a greater degree than flow rate and volume (Poindexter and Perrier 1980). As the ponded area increases, fetch distances for possible wind-induced waves increase, and the potential for solids resuspension also increases. As average depths increase, the velocity is reduced. Consequently, the influence of wave action at the interface is reduced, and the potential for solids resuspension decreases.

97. Field observations of conditions at all the sites indicated light to moderate wind, with the exception of the Norfolk Site. Storm conditions were experienced at this site during the early sampling efforts. The Norfolk data for storm conditions indicate that field effluent suspended solids concentrations can be higher than the values predicted by the column test by a factor of 10 during storms. Designs for such extreme conditions would be overly conservative during almost all of the operating time.

98. The data shown in Column 8 of Table 9 indicate that the ratios of measured to predicted concentrations vary from 0.48 to 1.19. A set of recommended settling efficiency factors was selected based on these data for ponded areas less than or greater than 100 acres and average depths less than or greater than 2 ft. The recommended factors vary from 1.5 to 2.5 and are presented for purposes of consistency in Appendix B. These settling efficiency factors are considered sufficiently conservative for purposes of disposal area evaluations under normally encountered wind conditions.

99. The values of suspended solids concentrations from the column tests were corrected for settling efficiency using the appropriate values selected from Table B1 in Appendix B. The predicted effluent suspended solids concentrations as corrected are shown in Column 10 of Table 9 and are also plotted in Figure 17. In five of the six cases, the predicted concentrations are conservative estimates of the measured field effluent suspended solids concentrations. For these cases, the average ratio of predicted to measured concentrations of suspended solids is 1.5. The procedures described above for considering settling efficiency are based on engineering judgment and limited field and laboratory data. For this reason it is recommended that as column test data and field data from additional sites become available, the procedures be refined as appropriate.

Zone Settling Test Verification

Field testing sites

100. Laboratory and field studies appropriate for verification of the zone settling tests are available from the following dredging projects:

a. Black Rock Harbor (1982)

b. Mobile Harbor (1978)

These projects are in saltwater environments whose sediments exhibit zone settling characteristics in laboratory column tests. Field data required to produce predictions to compare with the results of zone settling tests include the flow rate into the containment area and the ponded surface area. Effluent suspended solids concentrations are necessary for the comparison itself. Montgomery (1978) concluded that an effluent suspended solids concentration less than 1,000 mg/ℓ indicated that adequate surface area for zone settling was available. This criterion will be used as the verification requirement in the discussion that follows.

Laboratory studies

101. Laboratory settling tests for these two sediments were performed in the standard 8-in.-diam settling column in accordance with the laboratory procedures discussed in Part III and Appendix A of this report. Analysis of zone settling characteristics requires a series of column tests to determine zone settling velocity as a function of initial slurry concentration. ADDAMS-generated curves for the laboratory data are presented in Appendix D.

ADDAMS design

102. The zone settling and PROJ routines of ADDAMS' sedimentation design module (SETT) were applied to laboratory zone settling data to calculate clarification areas. Output listings for the Black Rock and Mobile Projects are shown in Tables 10 and 11, respectively. Input data were based on flow and surface area information collected during the field investigations.

103. ADDAMS calculates a value for ponded surface area for a design controlled by thickening and for a design controlled by clarification. The thickening-controlled design uses information from the zone settling and compression tests to calculate the area required for concentration of settled solids to the design solids concentration C_d (see Appendix B). Values of required area calculated for the clarification-controlled design are based on

Table 10

ADDAMS Zone Settling Design for Black Rock Harbor

SUMMARY OF INPUT DATA		
CHANNEL SEDIMENT VOLUME	(TCY) =	6.00
DIKE CREST HEIGHT	(FEET) =	10.00
EFFLUENT SOLIDS CONCENTRATION	(GPL) =	1.00
TOTAL SURFACE AREA	(ACRE) =	1.00
DISCHARGE FLOW RATE	(CFS) =	1.50
DISCHARGE PIPE DIAMETER	(FEET) =	.50
DISCHARGE VELOCITY	(FPS) =	15.00
PERCENT OF SURFACE AREA PONDED	(%) =	100.00
INFLUENT SOLIDS CONCENTRATION	(GPL) =	60.70
HYDRAULIC EFFICIENCY	(NONE) =	1.00
PONDED WATER DEPTH	(FEET) =	1.00
INITIAL VOID RATIO	(NONE) =	5.76
SPECIFIC GRAVITY	(NONE) =	2.44
COARSE-GRAINED FRACTION	(%) =	.00
EFFECTIVE DREDGING TIME	(%) =	100.00
OPERATING TIME PER DAY	(HPD) =	24.00
FREEBOARD HEIGHT	(FEET) =	2.00

ANALYSIS OF ZONE (TYPE 3) SETTLING TESTS

THICKENING DESIGN

PONDED SURFACE AREA (ACRES) = 9.47 <--- CALCULATED VALUE

VOLUMETRIC FLOW RATE(CFS) = 1.50

AVERAGE VOID RATIO IN DA AFTER DREDGING = 11.39

CLARIFICATION DESIGN

PONDED SURFACE AREA(ACRES) = .82 <--- CALCULATED VALUE

VOLUMETRIC FLOW RATE(CFS) = 1.50

Table 11

ADDAMS Zone Settling Design for Mobile Harbor

SUMMARY OF INPUT DATA		
CHANNEL SEDIMENT VOLUME	(TCY) =	500.00
DIKE CREST HEIGHT	(FEET) =	9.00
EFFLUENT SOLIDS CONCENTRATION	(GPL) =	1.00
TOTAL SURFACE AREA	(ACRE) =	85.00
DISCHARGE FLOW RATE	(CFS) =	47.50
DISCHARGE PIPE DIAMETER	(FEET) =	2.00
DISCHARGE VELOCITY	(FPS) =	15.00
PERCENT OF SURFACE AREA PONDED	(%) =	100.00
INFLUENT SOLIDS CONCENTRATION	(GPL) =	145.00
HYDRAULIC EFFICIENCY	(NONE) =	.44
PONDED WATER DEPTH	(FEET) =	2.00
INITIAL VOID RATIO	(NONE) =	2.50
SPECIFIC GRAVITY	(NONE) =	2.71
COARSE-GRAINED FRACTION	(%) =	15.00
EFFECTIVE DREDGING TIME	(%) =	100.00
OPERATING TIME PER DAY	(HPD) =	12.00
FREEBOARD HEIGHT	(FEET) =	2.00

ANALYSIS OF ZONE (TYPE 3) SETTLING TESTS

THICKENING DESIGN

PONDED SURFACE AREA (ACRES) = 27.97 <--- CALCULATED VALUE

VOLUMETRIC FLOW RATE(CFS) = 47.00

AVERAGE VOID RATIO IN DA AFTER DREDGING = 6.76

CLARIFICATION DESIGN

PONDED SURFACE AREA(ACRES) = 33.05 <--- CALCULATED VALUE

VOLUMETRIC FLOW RATE(CFS) = 47.00

the zone settling velocity at the field influent solids concentration. The area required for thickening for the Black Rock sediment was much greater than the area required for clarification. The clarification area was the greater area for the Mobile sediment.

104. The area required for thickening Black Rock was greater because the shape of the solids loading curve and the assumed value of the design solids concentration C_d dictated that ADDAMS select a solids loading value S_d much greater than the solids loading value at the field influent solids concentration, which is used for the clarification-controlled design. The value of C_d was too small to allow a tangent to be constructed to the solids loading curve, as required for the thickening design explained in Appendix B. In this case, the current version of ADDAMS selects a worst case value of S_d, resulting in the higher thickening area. The organic nature of the Black Rock sediment, the low influent solids concentration, and the relatively short project duration are responsible for the deviations from the typical settling theory for dredged material.

Results of field investigations

105. Black Rock Harbor. The containment area at Black Rock was designed and constructed specifically for evaluations of dredged material settling behavior. The approximately 220- by 150-ft containment area had a surface area of 0.83 acre. Dredged material was pumped from scows through a 6-in. pipe to the containment area over a period of about 15 days. Pumping was intermittent and averaged less than 15 hr per day. A retention time of 8 hr in the containment area was estimated, based on a dye study. The average flow, 1.5 cfs, was estimated using the measured retention time, the surface area, and an average depth of about 1 ft.

106. The design surface area for clarification from ADDAMS, 0.82 acre, was essentially equal to the actual surface area available at the site. This represents the best comparison available for assessing zone settling design procedures. Effluent suspended solids concentrations measured at the containment area weir averaged 173 mg/ℓ. This concentration is well below Montgomery's 1 g/ℓ criterion for effective zone settling. In one respect, one might conclude that the zone settling test is too conservative. However, Table 9 shows that Black Rock's effluent suspended solids concentration was much greater than concentrations from other saltwater sites, where more

surface area was available. It is possible that the limiting surface area of the Black Rock Site may have caused the higher effluent solids concentrations.

107. Mobile Harbor. The site selected to provide field data for evaluation of the saltwater design procedures was the Upper Polecat Bay Disposal Area shown in Figure 18. This is an 85-acre site located in Mobile Harbor. The dikes at this site were improved and increased in height using dewatered dredged material from past disposal activities at the site. A 48-ft weir was installed to accommodate the effluent. Based on preliminary calculations using the design methodology, the weir was set at an elevation at the beginning that provided for at least 2 ft of depth throughout the disposal activity. A 24-in. hydraulic pipeline dredge was used to dredge the material from the Mobile River.

108. ADDAMS calculations based on zone settling tests for this site determined that an area of 27.97 acres was required for thickening and an area of 33.05 acres was required for clarification. Therefore, the 85-acre site was too large to provide good comparison data for verification of the design procedures. However, it was adequate to provide data on dredged material concentrations during the disposal activity to compare with the concentrations determined in the laboratory column sedimentation tests using Mobile Harbor sediments.

109. Evaluation of sedimentation basin efficiency. Effluent suspended solids concentrations were determined and a dye tracer test was performed at the Mobile Harbor Site to evaluate its performance. It was determined from field observations during disposal that effluent was coming through the cracks in the 2- by 8-in. weir boards as well as over the weir. The effluent sampling program was developed to evaluate the suspended solids concentrations in the leakage through the weir as well as from flow over the weir. The mean suspended solids concentration measured during disposal from effluent over the weir was 0.215 g/ℓ (Figure 19). Samples from the combined flow over and through the weir produced a larger mean value of 0.332 g/ℓ, with a much wider standard deviation (Figure 19). The design methodology indicated that suspended solids could be reduced to a level <1 g/ℓ at the Mobile Harbor Site. The field concentrations of <1 g/ℓ verify the design methodology to a degree. However, because the site was larger than that calculated by the design methodology, the effluent solids concentrations would be expected to be less

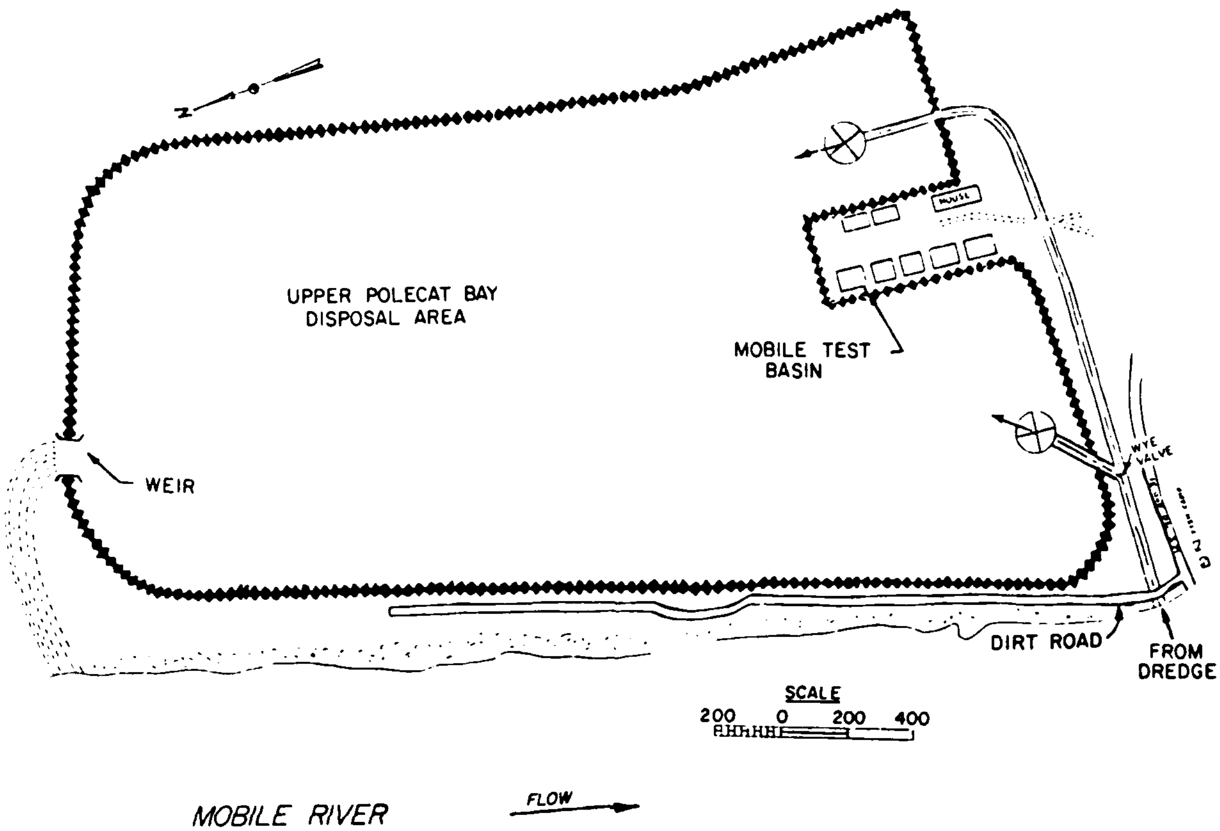
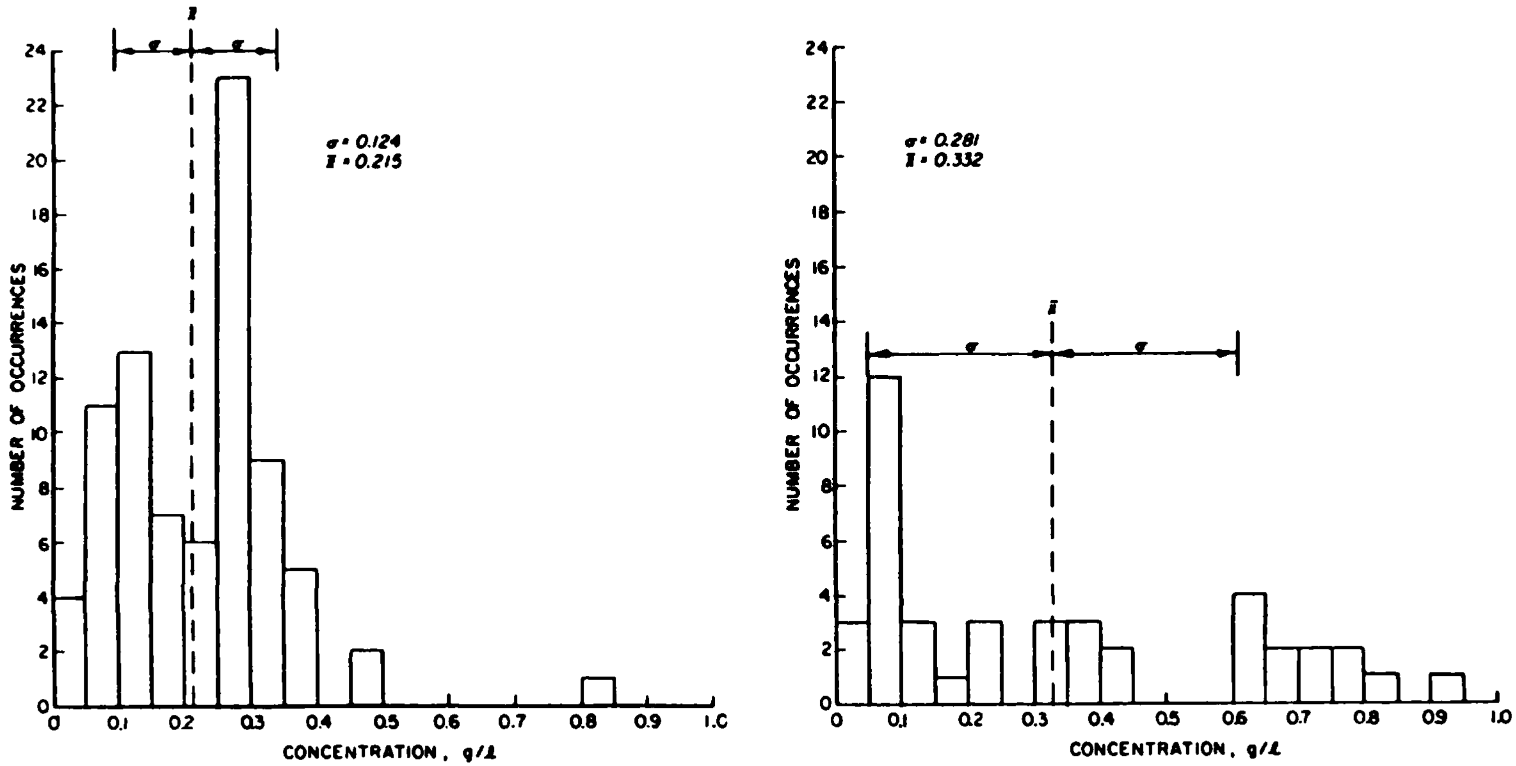


Figure 18. Upper Polecat Bay Disposal Area for Mobile Harbor (Montgomery 1979)



a. EFFLUENT FROM FLOW OVER WEIR

b. EFFLUENT FROM FLOW OVER AND THROUGH WEIR

Figure 19. Histograms of effluent suspended solids, Upper Polecat Bay, Mobile Harbor (Montgomery 1979)

than predicted for the 30- to 33-acre calculated area, so verification of the saltwater environment design methodology was limited.

110. Dye tracer tests were performed to evaluate the residence time of fluid in the Mobile Harbor Site. This test indicated that the actual detention time in the site was about 47 percent of the theoretical detention time. This site had a much better mean residence time than the other disposal areas investigated. The reason for this is not evident. The length-to-width ratio for the site was about 1.8. However, considerable longitudinal dispersion was present, as indicated by the spread of the tracer curve (Montgomery 1978).

Summary of zone settling verification

111. Field investigations at Black Rock Harbor and Mobile Harbor supported application of zone settling design methodology to the design of dredged material containment areas. Table 12 compares field results to design data derived from laboratory settling tests.

Table 12

Comparison of Zone Settling Design to Field Observations

Site (Year Tested)	ADDAMS Design for Containment Area, acres		Actual Area acres	Effluent Suspended Solids mg/ℓ
	Thickening	Clarification		
Black Rock Harbor (1982)	9.5	0.82	0.83	173
Mobile Harbor (1978)	28	33	85	332

PART V: FIELD VERIFICATION OF STORAGE ESTIMATES

112. Field data collected for the purpose of verifying the predictions of laboratory zone settling and compression tests are available for the Mobile Harbor (1978) sediment and the Black Rock Harbor sediment (1982).

Mobile Harbor Study

113. The Mobile Harbor investigation was conducted and reported by Montgomery (1978). This discussion on initial storage estimates is based primarily on Montgomery's observations. The purpose of Montgomery's study was to devise and verify a design method for containment areas receiving saltwater sediments. This was accomplished by comparing laboratory compression settling data to settling data from a field test pit and the actual containment area. A description of the containment area was given in Part IV.

114. Evaluation of dredged material concentration in basin. A sampling schedule was developed to provide for the collection of dredged material samples at a number of sampling points within the basin during disposal. The disposal activity covered a period of 23 days. During this period samples were taken at various depths. The data shown in Figure 20 are averages of solids concentrations measured at several depths at three sampling points located near the weir. These data show that the water above the solids interface in the basin was low in suspended solids at all times during the disposal activity, and that the solids concentration increased with time and depth below the interface. These points were sampled again 124 days after the disposal activity, and the average solids concentration had increased from about 300 to 690 g/ℓ.

115. Field and laboratory data for Mobile Harbor are compared in Figure 21. The field data were obtained from sampling of the containment area at Upper Polecat Bay and the Mobile Test Basin (30 ft by 30 ft). This test basin is located at the south end of the containment area, as shown in Figure 18. The laboratory data were obtained from column sedimentation tests described in Part III. The 8-in. column sedimentation test was performed according to the recommended test procedures in Appendix A using Mobile Harbor sediments. An experiment was designed to simulate actual field loading rates in the laboratory sedimentation columns. A schematic diagram of the experiment is shown in

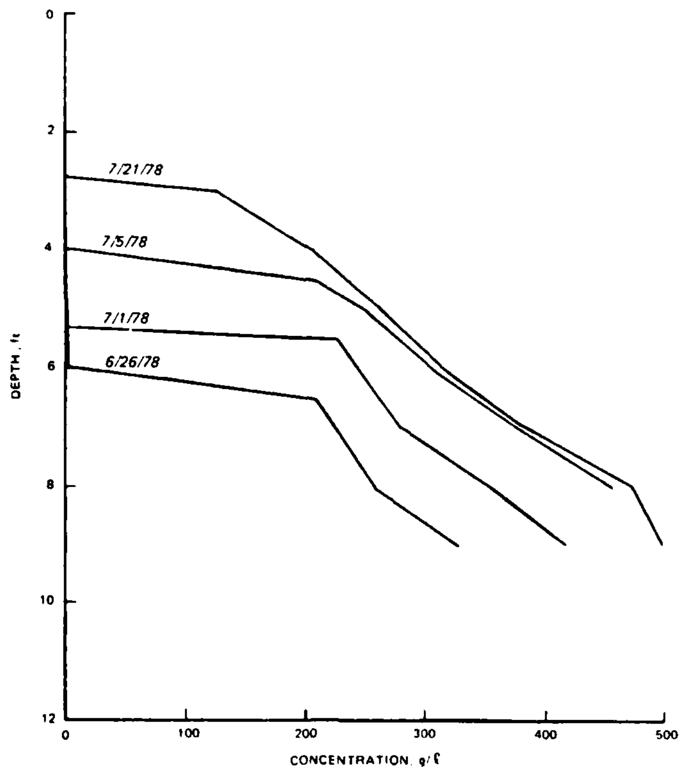


Figure 20. Suspended solids concentration versus depth at site near weir, Upper Polecat Bay, Mobile Harbor (Montgomery 1979)

Figure 22. The loading rate for the Upper Polecat Bay Disposal Area was determined, and an attempt was made to simulate it in loading the columns. Because of the high slurry concentration (145 g/ℓ), the pumping rates could not be reduced to the level that simulated actual field loading. The columns were loaded each day with the quantity of slurry that simulated the daily loading rate at Upper Polecat Bay. However, the rate of application could not be simulated. The 36-in. column was loaded over a period of about 6 hr each day using a varistaltic pump. The pumping rate could not be reduced further while pumping the dredged material slurry. Therefore, the 8-in. column had to be loaded by pouring the slurry in each morning.

116. The suspended solids concentration was about the same for incremental loading tests performed in the 36-in. and 8-in. columns. At the end of tests covering 31 days, the average concentrations in the 36-in. and 8-in. columns were 334 and 332 g/ℓ, respectively (Figure 21).

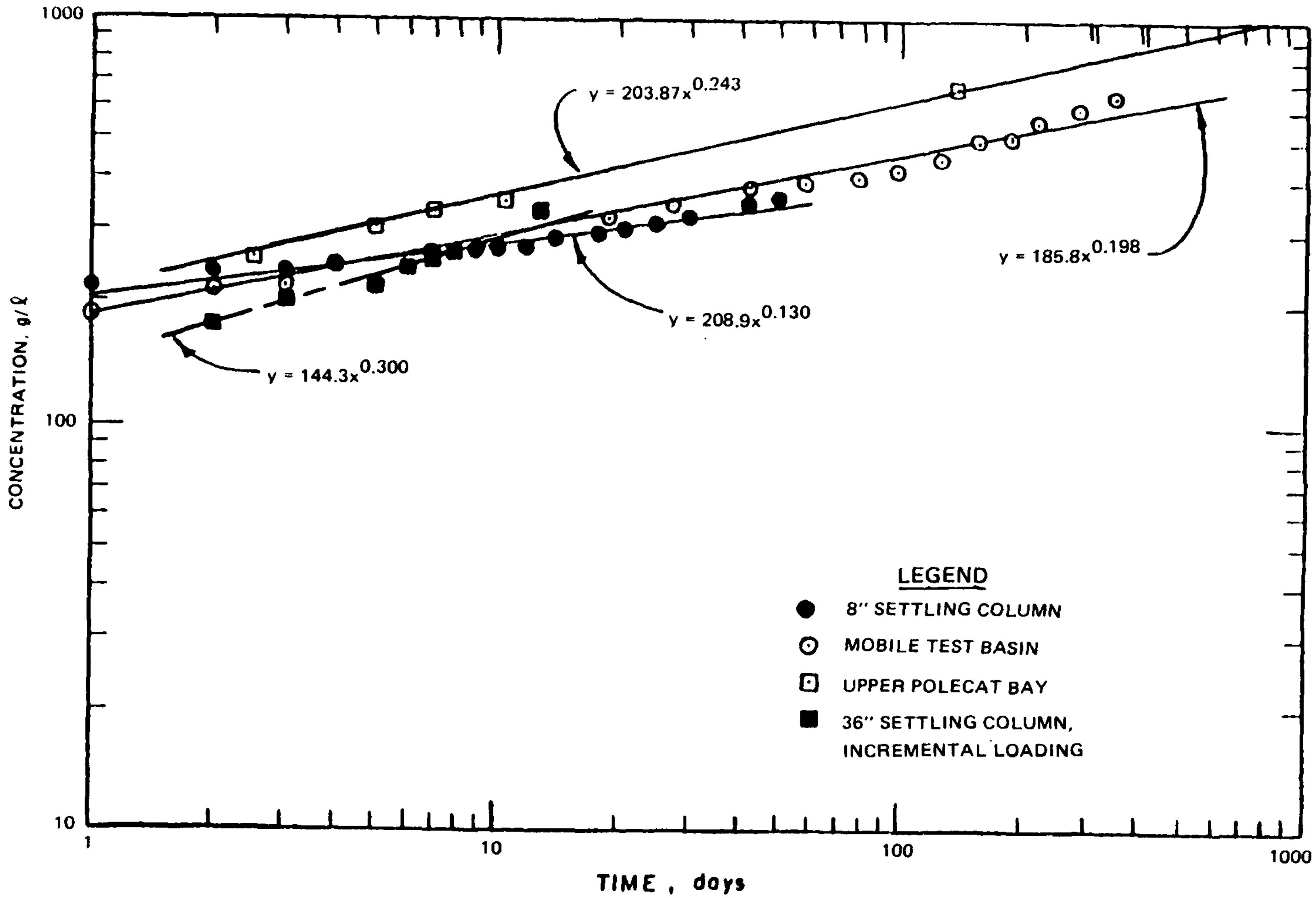


Figure 21. Correlation of field and laboratory solids concentration data for Mobile Harbor (Montgomery 1979)

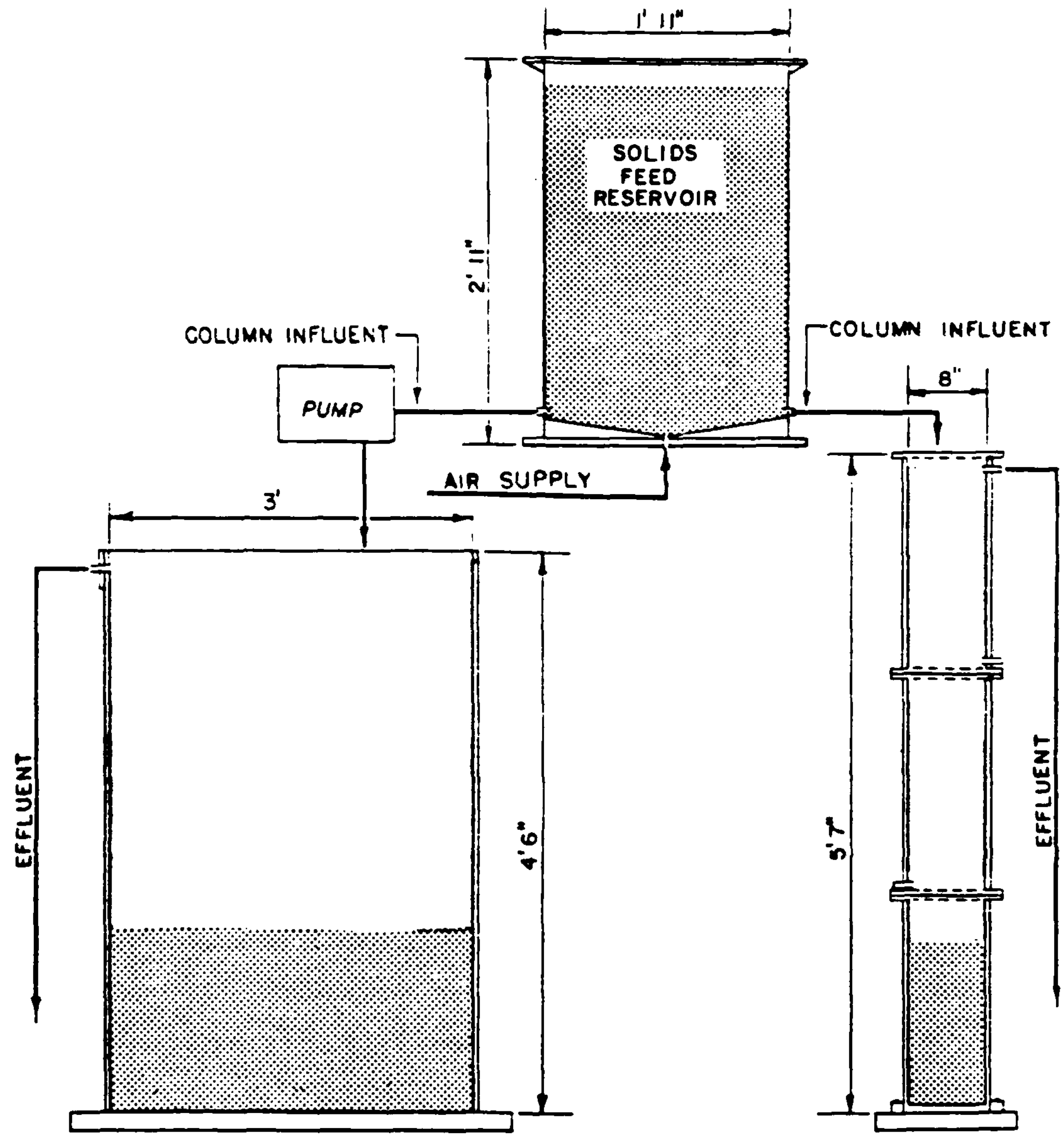


Figure 22. Column sedimentation test equipment used for Mobile Harbor sediment (Montgomery 1979)

117. Statistical analyses were performed to determine whether there are significant differences between the field and laboratory data. The test was applied to the null hypothesis that the values being compared are drawn from the same population. The slope and intercept from the Upper Polecat Bay regression equation were compared with the slopes and intercepts from the 8-in. and 36-in. column regression equations. The analyses for the 8-in. column data indicated that there was not a significant difference in the regression equations at a 5-percent level of significance. The analyses for the

36-in. column data indicated that there was a significant difference in intercepts for the two equations at the 5-percent level of significance. However, there was not a significant difference in the slopes at this level of significance. These data indicate that concentration design parameters can be obtained from the long-term column laboratory test using an 8-in.-diam column.

Black Rock Harbor Study

118. During 1982, a number of verification studies were conducted at Black Rock Harbor, Bridgeport, Connecticut. Included in these studies were analyses for effluent suspended solids concentrations and for solids concentrations in the settled solids on the bottom of the containment area. Comparison of laboratory and field effluent suspended solids concentrations was discussed in Section IV. This section will compare the results of the compression settling test to field values.

Compression settling tests

119. A 15-day compression test in an 8-in.-diam by 6-ft-tall column was performed in the laboratory on a Black Rock Harbor sediment sample. The field study consisted of determining solids concentrations of settled dredged material in a 1-acre containment area. Field sampling began 7 days after dredged material was first placed in the containment area and continued daily until Day 15. Samples were collected from middepth and from near the bottom of the settled dredged material. The bottom solids concentration is used for this study.

120. Figure 23 illustrates how the laboratory results compare with the field results. Field results were plotted using the beginning of field sampling as the initial time. This provided good correlation to the laboratory results. The laboratory and field curves in Figure 23 converge during the 10- to 15-day time period. The field analysis is not exactly the same as the lab study, since all the material was added to the lab column at time zero. Selection of the first day of field sampling as the initial time can be justified on the basis that the containment area was loaded intermittently during the first 7 days, and the depth of settled dredged material was too shallow to represent compression settling.

121. The significance of this comparison of laboratory and field data is its verification of the validity of the proposed method for the design of a

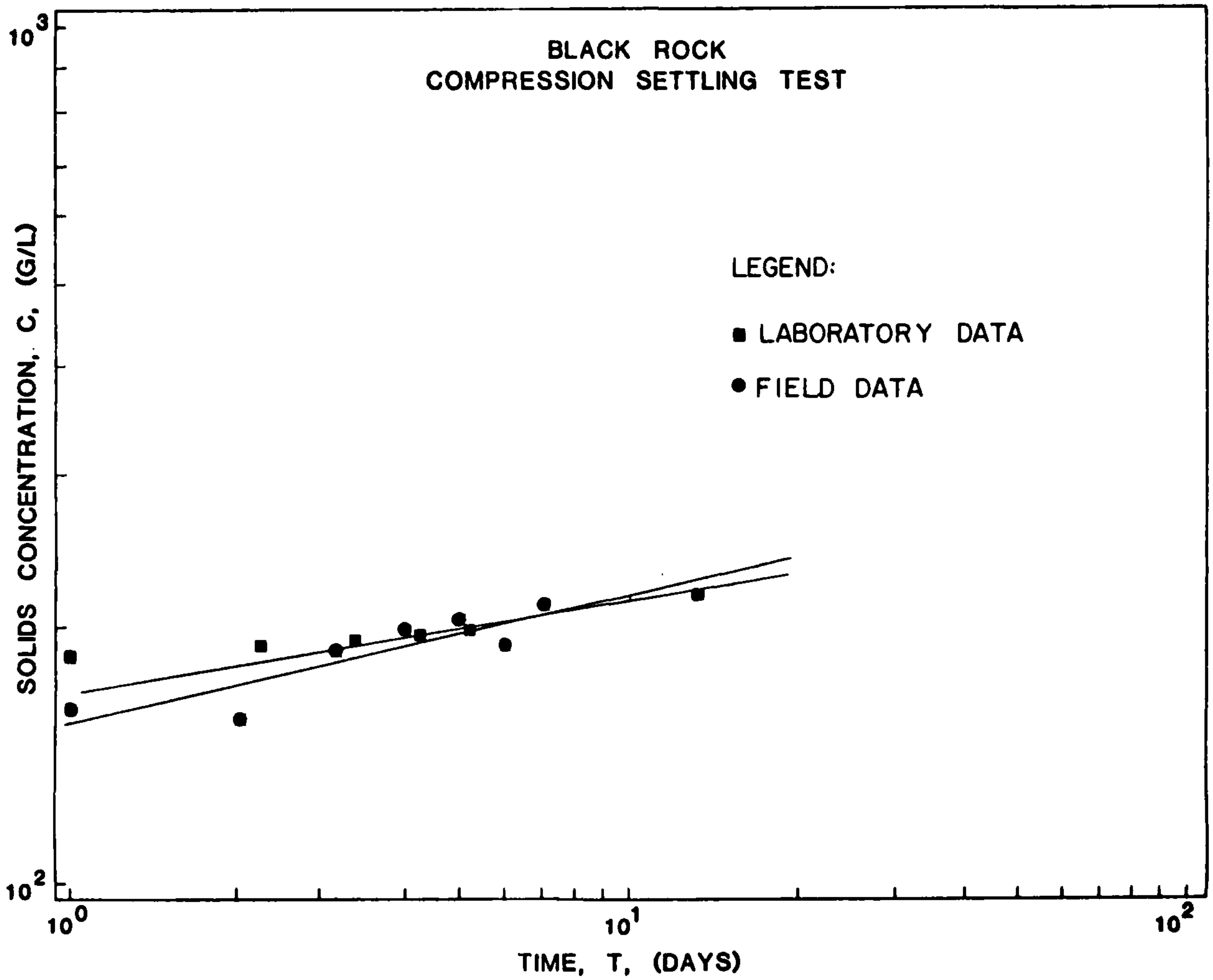


Figure 23. Correlation of field and laboratory solids concentration data for Black Rock Harbor

containment area for initial storage of the dredged material. Appendix B describes the design procedure. It requires that the designer first estimate the expected duration of the dredging project, and, secondly, predict from the laboratory compression test the solids concentration at a time equal to half the project duration.

122. Table 13 compares solids concentrations at 10, 15, 20, and 30 days from the plots of data for the laboratory and field study compression tests. The percent difference between the two tests is less than 1 percent for the four times selected for comparison. This verifies that the conditions in the laboratory compression test are good representations of field conditions, and

Table 13

Laboratory Versus Field Values for Black Rock

Compression Settling Analysis

Day	Concentration, g/ℓ Laboratory	Field
10	217	218
15	232	232
20	243	243
30	259	258

that the results of the laboratory compression test can be used to predict the concentrations of the settled dredged material in the field.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

123. Laboratory settling tests conducted on 28 different sediment samples demonstrated that different sediment samples exhibit a wide range of settling properties. Therefore, discrete laboratory testing on a sediment-specific basis is necessary to predict settling properties necessary for design.

124. Based on 6 years of laboratory and field experience, the laboratory procedures described in this report are currently the best methods available for determining the settling properties of dredged material.

125. The computer program ADDAMS is a useful tool for analyzing the data from laboratory column settling tests and for designing containment areas for solids retention.

126. Field studies of effluent suspended solids concentrations in containment areas verified the predictive ability of the design procedures based on the flocculent settling tests for the range of solids concentrations and field conditions studied.

127. Comparison of the results from laboratory tests for zone and compression settling to the results from field studies at two sites verified the ability of these laboratory tests to predict levels of zone settling for solids removal and initial solids storage. Additional field data need to be obtained under varying operational conditions, for a wider range of solids concentrations, and for differing sediment characteristics in order to confirm the applicability of these tests to dredged material settling behavior.

Recommendations

128. Design of hydraulically filled dredged material containment areas to ensure solids retention is site dependent and should be based on data from laboratory settling tests. The wide range of settling properties documented by this study suggests that the use of literature values or experience from previous dredging projects could produce poorly engineered containment areas.

129. The procedures discussed in this task should be used for the design of containment areas for solids retention.

130. The data base of settling test results compiled by this task should be expanded as additional laboratory tests are performed and as additional field data from applications of the design procedures become available. Data to further verify the zone and compression settling test procedures are especially needed. US Army Engineer Districts are requested to report on their experience with the use of laboratory settling data and the ADDAMS computer program for design purposes. The Districts are asked for their observations and data on containment areas that have been designed using these procedures.

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APPENDIX A: SETTLING TEST PROCEDURES

APPENDIX A: SETTLING TEST PROCEDURES*

PART I: TESTING EQUIPMENT AND PROCEDURES

Test Objective

1. The objective of running settling tests on sediments to be dredged is to define, on a batch basis, their settling behavior in a large-scale, continuous-flow dredged material containment area. The tests provide numerical values for the design criteria which can be projected to the size and design of the containment area.

Test Equipment

2. The settling column shown in Figure 2 of the main text should be used for dredged material settling tests (Montgomery 1978).** The column is constructed of 8-inch Plexiglas tubing and can be sectioned for easier handling and cleaning. Shop drawings of the column with bills of materials are available from the WES Environmental Laboratory.

Samples

3. Samples used to perform settling tests should consist of fine-grained (<No. 40 sieve) material. If coarse-grained (>No. 40 sieve) material present in the sample is less than 10 percent (dry weight basis), separation is not required prior to sedimentation testing. A composite of several sediment samples may be used to perform the tests if this is thought to be more representative of the dredged material. Approximately 15 gal of sediment is usually required for the tests.

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* Material in this Appendix was adapted from Draft EM 1110-2-5027 "Confined Disposal of Dredged Material" (US Army Engineer Waterways Experiment Station 1985).

** References cited in this appendix are included in the list of References which follows the main text of the report.

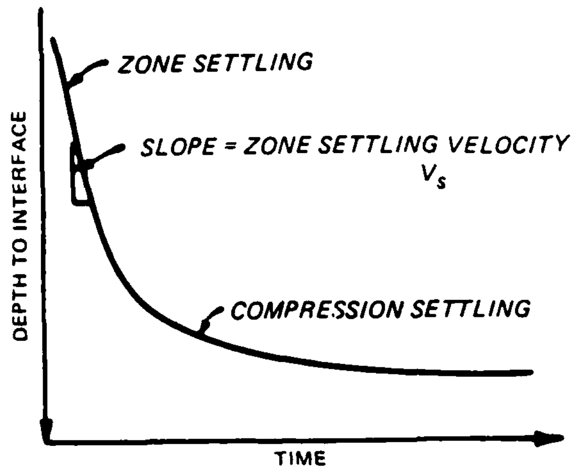

Figure A1. Conceptual plot of interface height versus time

Test Procedures

Pilot test

4. A pilot test conducted in a small graduated cylinder (1ℓ is satisfactory) is a useful method for determining whether flocculent settling or zone settling processes will prevail during the initial settling. The pilot test should be run at a slurry concentration of approximately 150 g/ℓ. If an interface forms within the first few hours of the test, the slurry mass is exhibiting zone settling, and the fall of the interface versus time should be recorded. The curve will appear as shown in Figure A1. The break in the curve will define the concentration at which compression settling begins. Only concentrations lower than this transition calculation should be used for the zone settling test series in the 8-inch column. If no break in the curve is evident, the material began settling in the compression zone, and the pilot test should be repeated at a lower slurry concentration.

5. It should be emphasized that use of a small cylinder as in the pilot test is not acceptable for use in design. Wall effects for columns of small diameter affect zone settling velocities, and data obtained using small-diameter columns will not accurately reflect field behavior.

6. If no interface is observed in the pilot test within the first few hours, the slurry mass is exhibiting flocculent settling. In this case, the pilot test should be continued until an interface is observed between the turbid water above and more concentrated settled solids below. The concentration

of the settled solids (computed assuming zero concentration of solids above) is an indication of the concentration at which the material exhibits compression settling.

Required number of column loadings for tests

7. Three types of settling tests may be needed to fully define the settling properties of the dredged material. However, in many cases the 8-in. settling column used for the settling tests need only be loaded with slurry once. A compression settling test is needed to define the volume which will be occupied in the disposal area by a newly deposited dredged material layer. Also, a flocculent settling test for either the slurry mass or for the supernatant water above any interface is required to predict effluent suspended solids concentrations. Both of these tests should be conducted at a slurry concentration equal to the expected influent concentration. Therefore, only one loading of the test column would be required to collect data for both purposes. A series of zone settling tests is required to define the minimum required surface area needed for effective zone settling. For the zone settling test series, the pilot test will define the highest concentration which should be used for the series. If the column is initially loaded for this condition, the same material in the column can be used for the remaining tests by draining appropriate volumes of slurry (remixed following a test by agitating with compressed air) and replacing the drained slurry with an equal volume of water of appropriate salinity.

PART II: SETTLING TESTS

Flocculent Settling Test

8. The flocculent settling test consists of measuring the concentration of suspended solids at various depths and time intervals in a settling column. If an interface forms near the top of the settling column during the first day of the test, sedimentation of the material below the interface is described by zone settling. In that case, the flocculent test procedure should be continued only for that portion of the column contents above the interface.

9. Information required to design a containment area in which flocculent settling occurs can be obtained using the following procedure:

- a. Use a settling column such as the one shown in Figure 2 in the main text. The slurry depth used in the test column should approximate the effective settling depth of the proposed containment area. A practical upper limit on the depth of the test is 6 ft. The column should be at least 8 in. in diameter, with sample ports at 0.5-ft intervals (minimum). The column should have provisions for slurry agitation with compressed air from the bottom to keep the slurry mixed during the column filling period.
- b. Mix the sediment slurry to the desired suspended solids concentration selected to represent the expected concentration of the dredged material influent C_i. The slurry should be mixed in a container with sufficient volume to fill the test column. Field studies indicate that for maintenance dredging the fine-grained material concentration will average about 150 g/ℓ. This should be the concentration used in the test if better data are not available.
- c. Pump or pour the slurry into the test column, using compressed air to maintain a uniform concentration during the filling period.
- d. When the slurry is completely mixed in the column, cut off the compressed air and immediately draw off samples at each sample port and determine their suspended solids concentration. Use the average of these values as the initial slurry concentration at the start of the test. The test is considered initiated when the initial samples are drawn.
- e. If an interface has not formed on the first day, flocculent settling is occurring in the entire slurry mass. Allow the slurry to settle and withdraw samples from each sampling port at regular time intervals to determine the suspended solids concentrations. Substantial reductions of suspended solids will occur

during the early part of the test, but reductions will lessen at longer retention times. Therefore, the intervals between sampling can be extended as the test progresses. Recommended sampling intervals (in hours) are: 1, 2, 4, 6, 12, 24, 48, etc. until the end of the test. As a rule, a 50-ml sample should be taken from each port. Continue the test until an interface of solids can be seen near the bottom of the column and the suspended solids concentration in the fluid above the interface is <1 g/ℓ. Tabulate test data and use them to plot a concentration profile diagram like the one shown in Figure A2. Examples are shown in Appendix D.

f. If an interface forms the first day, zone settling is occurring in the slurry below the interface, and flocculent settling is occurring in the supernatant water. For this case, samples should be extracted from all side ports above the falling interface. The first of these samples should be extracted immediately after the interface has fallen sufficiently below the uppermost port to allow extraction without disturbing the slurry below the interface. This sample can usually be extracted within a few hours after initiation of the test, depending on the initial slurry concentration and the spacing of ports. Record the time of extraction and port depth below the surface for each port sample taken. As the interface continues to fall, extract samples from all ports above the interface at regular time intervals. As an alternative, samples can be taken above the interface at the desired depths using a pipette or syringe and tubing. As before, a suggested sequence of sampling intervals would be 1, 2, 4, 6, 12, 24, 48, 96 hr, etc. The samples should continue to be taken until the suspended solids concentration of the extracted samples shows no decrease. For this case, the suspended solids concentrations in the samples should be less than 1 g/ℓ, and filtration will be required to determine the concentrations. Tabulate the data, and plot a concentration profile diagram as shown in Figure A2. In computing the percentages remaining R for this case, the concentration of the first port sample taken above the falling interface is considered the initial concentration SS_o. Examples are shown in Appendix D.

Zone Settling Test

10. The zone settling test consists of placing a slurry in a sedimentation column, and measuring the height of the liquid-solids interface at various times. These data are plotted as depth-to-interface versus time. The slope of the constant settling velocity (straight-line) portion of the curve is the zone settling velocity, which is a function of the initial slurry concentration. A series of these tests is required if the material exhibits an

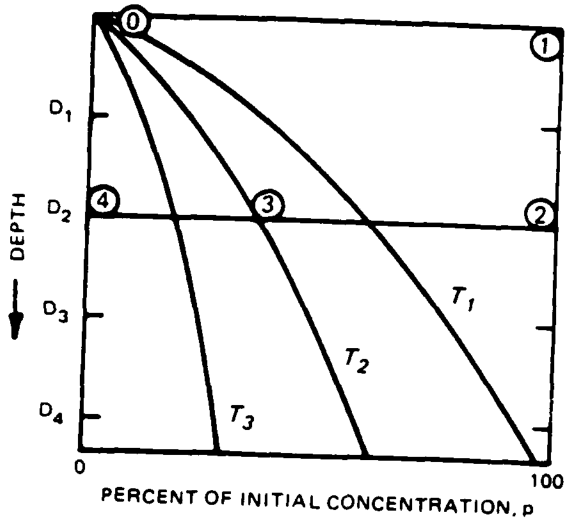

Figure A2. Conceptual concentration profile diagram

interface within the first day. The range of slurry concentrations used in the series should vary from a low of approximately 50 g/ℓ to a high concentration at which the slurry exhibits compression settling (determined by the pilot settling test) immediately.

11. Information required to design a containment area in which zone settling occurs can be obtained by using the following procedure:

a. Use a settling column such as the one shown in Figure 2 in the main text. It is important that the column diameter be sufficient to reduce the "wall effect," and that the test be performed with a test slurry depth near that expected in the field. Therefore, a 1-ℓ graduated cylinder should never be used to perform a zone settling test for sediment slurries representing dredged material.

b. Mix the slurry to the desired concentration and pump or pour it into the test column. Air may not be necessary to keep the slurry mixed if the filling time is less than 1 min.

c. Record the depth to the solid-liquid interface as a function of time. Measurements must be taken at regular intervals to gain data for plotting the depth-to-interface versus time curve as shown in Figure A1. It is important to take enough measurements to clearly define this curve for each test.

d. Continue the measurements until sufficient data are available to define the maximum point of curvature of the curve which plots depth-to-interface versus time for each test. The tests may require from 1 to 3 days to complete.

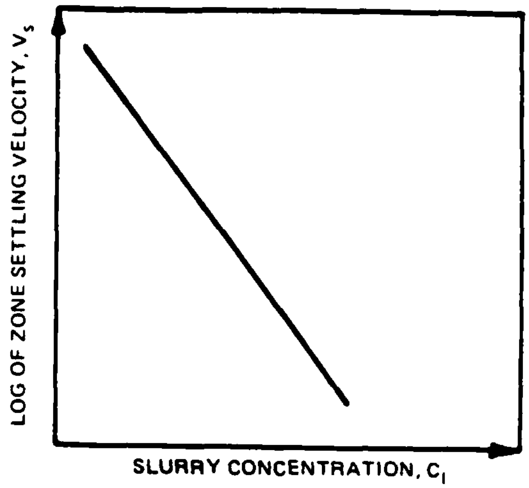

Figure A3. Conceptual plot of zone settling velocity versus concentration

e. Perform a minimum of four tests. Data from these tests are required to develop the curve of zone settling velocity versus concentration, as shown in Figure A3. Examples are shown in Appendix D.

Compression Settling Test

12. A compression settling test must be run to obtain data for estimating the volume required for initial storage of the dredged material. For slurries exhibiting zone settling, the compression settling data can be obtained from one of the series of zone settling tests, in which the depth of the interface versus time is recorded. The only difference is that the test is continued for a period of 15 days so that a relationship of concentration versus time in the compression settling range is obtained, as shown in Figure A4.

13. For slurries exhibiting flocculent settling behavior, the test used to obtain flocculent settling data can be used for the compression settling test if an interface is formed after the first few days of the test. If not, an additional test is required, with the initial slurry concentration for the test sufficiently high to initially induce compression settling. This concentration can be determined by the pilot test.

14. The following steps are used to develop the curve of concentration versus time:

a. Tabulate the interface depth H for various times of observation during the 15-day test period.

b. Calculate concentrations for various interface heights as follows:

$$C = \frac{C_i H_i}{H}$$

where

C = slurry concentration at time T, g/ℓ

C_i = initial slurry concentration, g/ℓ

H_i = initial slurry height, ft

H = height of interface at time T, ft

This assumes zero solids concentration in the water above the interface to simplify calculations.

c. Plot concentration versus time on log-log paper as shown in Figure A4.

d. Draw a straight line through the data points. This line should be drawn through the points representing the compression settling or consolidation zone, as shown in Figure A4.

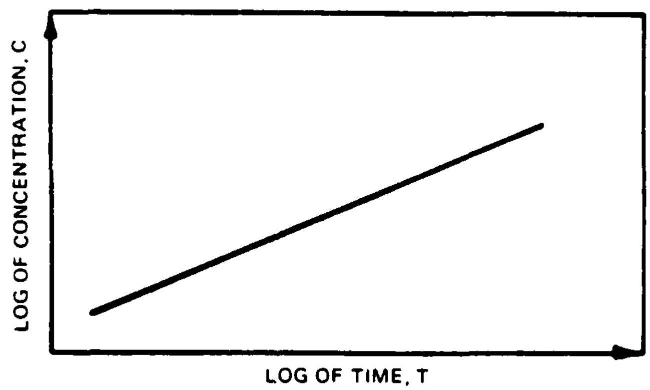

Figure A4. Conceptual time-versus-concentration plot

APPENDIX B: PROCEDURES FOR ESTIMATING SOLIDS RETENTION AND INITIAL STORAGE

APPENDIX B: PROCEDURES FOR ESTIMATING SOLIDS RETENTION AND INITIAL STORAGE*

PART I: BACKGROUND AND OBJECTIVES

1. This Appendix presents guidelines for designing a new containment area for suspended solids retention and for evaluating the suspended solids retention potential of an existing containment area. The focus in this section is on fine-grained dredged material. Guidelines presented here will provide the necessary guidance for designing a containment area of adequate area and volume for (a) retaining the solids within the containment area through settling, and (b) providing storage capacity of dredged solids for a particular continuous dredged material disposal activity. The major objective is to provide solids removal by the process of gravity settling to a level that permits discharge of the transporting water from the area. Although ponding is not feasible over the entire surface area of many sites, an adequate ponding depth must be maintained over the design surface area as determined by these design procedures to assure adequate retention of solids.

2. The generalized flowchart shown in Figure B1 illustrates the design procedures presented in the following paragraphs. The design procedures were adapted from procedures used in water and wastewater treatment and are based on field and laboratory investigations on sediments and dredged material at several active dredged material containment areas.

3. The design procedures presented here are for gravity settling of dredged solids. However, the process of gravity sedimentation will not completely remove the suspended solids from the containment area effluent since wind and other factors can resuspend solids and increase effluent solids concentration. The settling process, with proper design and operation, will normally provide removal of fine-grained freshwater dredged material down to a level of 1 to 2 g/ℓ or lower in the effluent. The settling process will usually provide removal of fine-grained saltwater dredged material down to a level of several hundred milligrams per liter or lower. If the required

* Material in this Appendix was adapted from Draft EM 1110-2-5027 "Confined Disposal of Dredged Material" (US Army Engineer Waterways Experiment Station 1985).

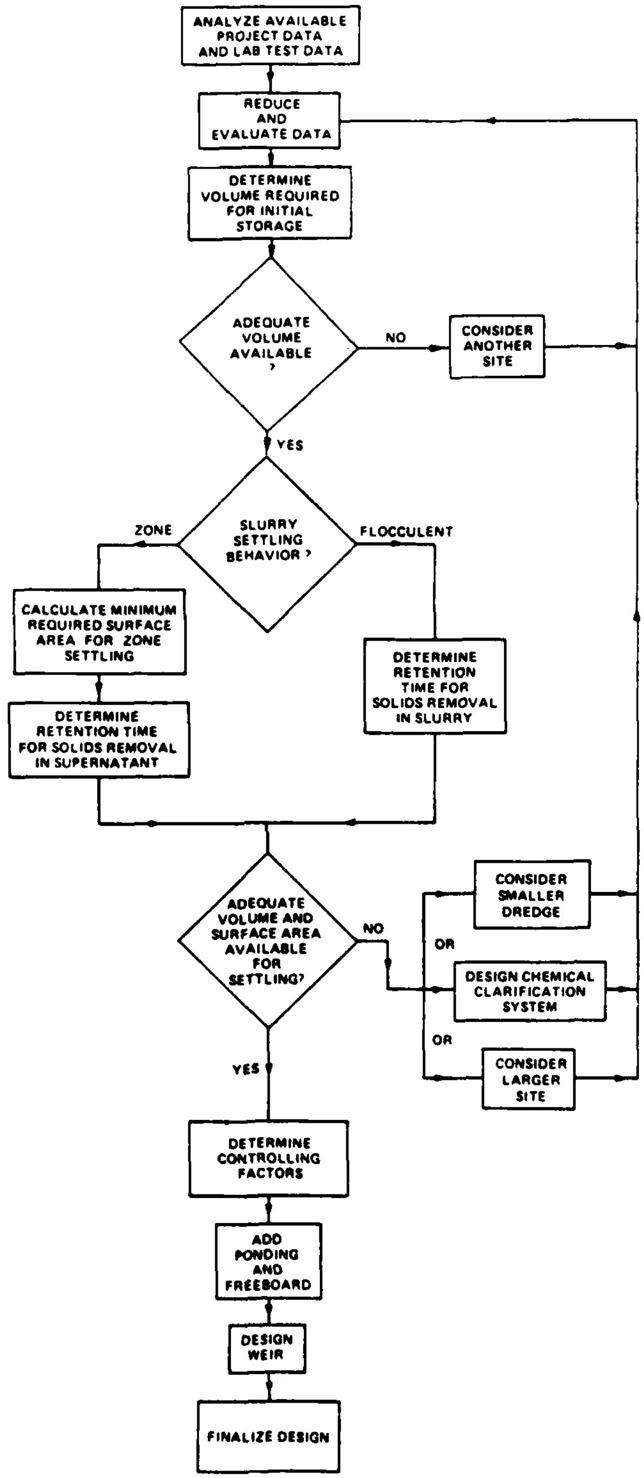

Figure B1. Flowchart of design procedure for settling and initial storage

effluent standard is not met by gravity settling, the designer must provide for additional treatment of the effluent; e.g., flocculation or filtration.

PART II: DATA REQUIREMENTS

4. The data required to use the design guidelines are obtained from field investigations, laboratory testing, project-specific operational constraints, and past experience in dredging and disposal activities. The types of data required are described in the following paragraphs.

In Situ Sediment Volume

5. The initial step in any dredging activity is to estimate the in situ volume of sediment to be dredged. Sediment quantities are usually determined from channel surveys on a routine basis by Corps District personnel.

Physical Characteristics of Sediments

6. Field sampling and sediment characterization should be accomplished using the laboratory tests described in engineer manuals. Adequate sample coverage of the area to be dredged is required to provide representative samples of the sediment. In situ water content of the fine-grained maintenance sediment is also required. Care must be taken in sampling to ensure that the water content is representative of the in situ conditions. Water content of representative samples w is used to determine the in situ void ratio e_i as follows:

$$e_i = \frac{wG_s}{S_D} \qquad \text{(B1)}$$

where

e_i = in situ void ratio of sediment

w = water content of the sample, percent

G_s = specific gravity of sediment solids

S_D = degree of saturation, percent (equal to 100 percent for sediments)

A representative value of the in situ void ratios is used later to estimate the volume for the containment area. Grain size analyses are used to estimate

the quantities of coarse- and fine-grained material in the sediment to be dredged.

Proposed Dredging and Disposal Data

7. The designer must obtain and analyze data concerning the dredged material disposal rate. For hydraulic pipeline dredges, the type and size of dredge(s) to be used, average distance to the containment area from the dredging activity, depth of dredging, and average solids concentration of the dredged material when discharged into the containment area must be considered. If the size of the dredge to be used is not known, the largest dredge size that might be expected to perform the dredging should be assumed. The time required for the dredging can be estimated based on past experience. If no data on past experience are available, Figure B2, which shows the relationship among solids output, dredge size, and pipeline length for various dredging depths, should be used. It was developed from data provided for Ellicott dredges (Palermo, Montgomery, and Poindexter 1978). For hopper dredges, an equivalent disposal rate must be estimated based on hopper or barge pump-out rate and travel time involved. Based on these data, the designer must estimate or determine containment area influent flow rate, influent suspended solids concentration, effluent flow rate (for weir sizing), effluent concentration allowed, and time required to complete the disposal activity. For hydraulic pipeline dredges, if no other data are available, an influent suspended solids concentration of 150 g/ℓ (14 percent by weight) should be used for design purposes. This value is based on a number of field investigations performed during the DMRP (Montgomery 1978).

Laboratory Settling Test Data

8. The guidelines for sedimentation tests are given in Appendix A. Depending on the results of the sedimentation tests, the dredged material will either settle by zone processes (common for saltwater sediments) or flocculent processes (common for freshwater sediments). Regardless of the salinity, flocculent processes determine the concentration of solids in the supernatant, from which the effluent comes.

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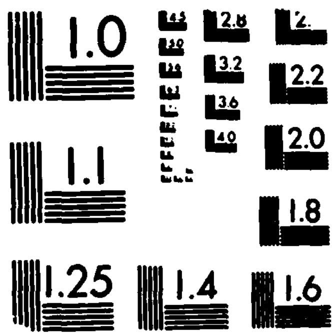

MICROCOPY RESOLUTION TEST CHART
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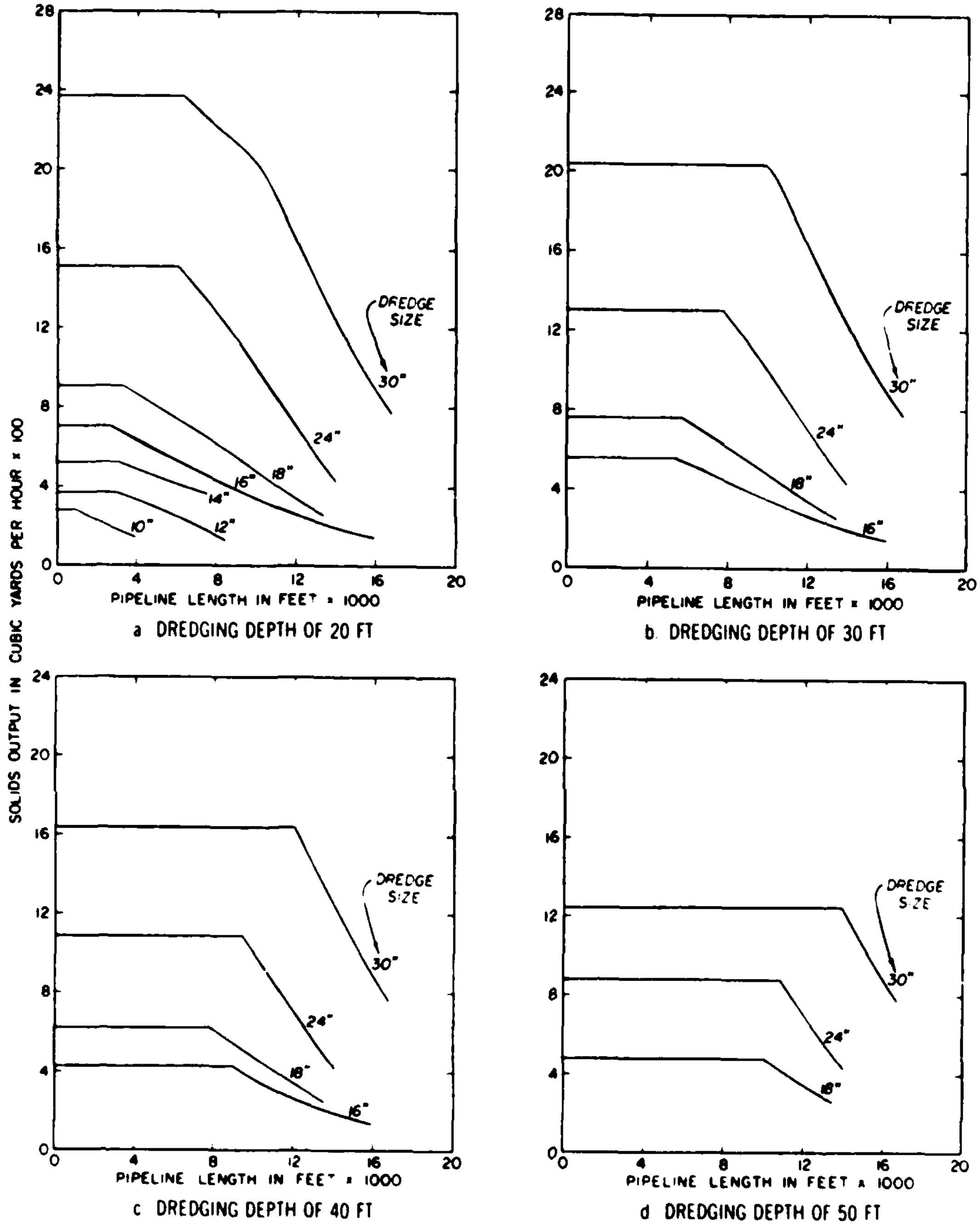

Figure B2. Relationships among solids output, dredge size, and pipeline length for various dredging depths (developed from data provided by Palermo, Montgomery, and Poindexter 1978)

PART III: SEDIMENTATION BASIN DESIGN

Selection of Ponding Depth

9. Before a disposal site can be designed for effective settling or before the required disposal area geometry can be finalized, a ponding depth during disposal H_{pd} must be assumed. The design procedures in the following paragraphs call for a ponding depth in estimating detention time necessary for effective settling. A minimum ponding depth of 2 ft should be used in the estimates. If conditions will allow for greater ponding depths throughout the operation, the greater value can be used. For most cases, the ponding depth can be maintained at a constant depth by raising the level of the overflow weir or pond surface as settled material accumulates in the sites. In some cases it may be desirable to begin operations with the maximum ponding depth possible. The disposal site should be designed in this case so that the ponding depth in the last stages of the disposal operation (as the site is filled) is great enough to maintain effective settling.

Calculation of Volume for Initial Storage

10. Containment areas must be designed to meet storage volume requirements for a particular disposal activity. The total volume required for a containment area includes volume for storage of dredged material, volume for sedimentation (ponding depths), and freeboard volume (volume above water surface). Volume required for storage of the coarse-grained (>No. 40 sieve) material must be determined separately, as this material behaves independently of the fine-grained (<No. 40 sieve) material.

Calculation of design concentration

11. The design concentration C_d is defined as the average concentration of the settled dredged material in the containment area at the end of the disposal activity and is estimated from the compression (15-day) settling tests described in Appendix A. This design parameter is required both for estimating the initial storage requirements and for determining the minimum required surface areas for effective zone settling. The following steps can be used to estimate average containment area settled concentrations from the compression settling test.

a. Compute settled concentration versus time for the compression settling test. Assume zero solids concentration in the water above the solids interface to simplify calculations. The following equation can be used to calculate concentrations for various interface heights:

$$C = \frac{C_i H_i}{H} \qquad \text{(B2)}$$

where

C = slurry concentration at time T, g/ℓ

C_i = initial slurry concentration, g/ℓ

H_i = initial slurry height, ft

H = height of interface at time T

b. Plot concentration versus time on log-log paper as shown in Figure A4.

c. Draw a straight line through the data points. This line should be drawn through the points representing the compression settling or consolidation zone, as shown in Figure A2.

d. Estimate the time of dredging by dividing the dredge production rate into the volume of sediment to be dredged. Use Figure B2 for estimating the dredge production rate if no specific data are available from past dredging activities. (Note that the curves in Figure B2 were developed for sand.) Total time required for dredging should consider anticipated down time.

e. Enter the concentration-versus-time plot as shown in Figure B3, and determine the concentration at a time T equal to half the time required for the disposal activity determined in step d.

f. The value determined in step e is the design solids concentration C_d.

Volume estimation

12. The volume computed in the following steps is the volume occupied by the dredged material in the containment area after the completion of a particular disposal activity. The volume is not an estimate of the long-term needs for multiple-disposal activities. Estimates for long-term storage capacity can be made using the procedures outlined in Cargill (1985). The procedures given below can be used to design for the initial volume required for one disposal activity. The design for initial storage may be a controlling factor regardless of the settling behavior exhibited by the material. If the material initially exhibits compression settling at the expected inflow

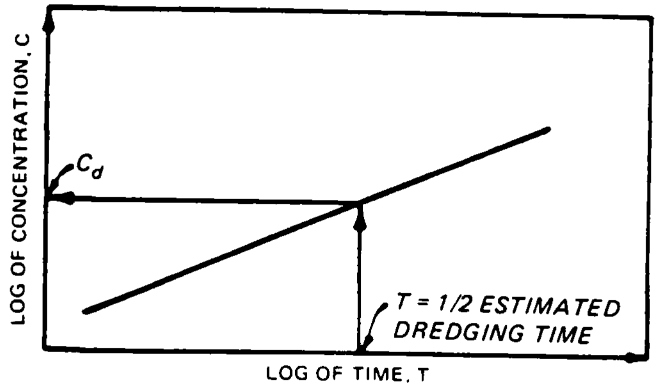

Figure B3. Conceptual time-versus-concentration plot

concentration, the design for initial storage is the only consideration. (This is expected to be an exceptional case.)

a. Compute the average void ratio of the fine-grained dredged material in the containment area at the completion of the dredging operation using the design concentration C_d determined above as the dry density of solids. Use the following equation to determine the void ratio:

$$e_o = \frac{G_s \gamma_w}{C_d} - 1 \qquad \text{(B3)}$$

where

e_o = average void ratio of the dredged material in the containment area at the completion of the dredging operation

γ_w = density of water, g/ℓ (normally 1,000 g/ℓ).

b. Compute the volume of the fine-grained channel sediments after disposal in the containment area:

$$V_f = V_i \frac{e_o - e_i}{1 + e_i} + 1 \qquad \text{(B4)}$$

where

V_f = volume of the fine-grained channel sediments after disposal in the containment area, ft^3

V_i = volume of the fine-grained channel sediments in situ, ft^3

c. Compute the volume required to store the dredged material in the containment area

$$V = V_f + V_{sd} \tag{B5}$$

where

V = volume of the dredged material in the containment area at the end of the dredging operation, ft^3

V_{sd} = volume of sand (compute using 1:1 ratio), ft^3

d. If there are limitations on the surface area available for disposal or if an existing disposal site is being evaluated, determine whether the site conditions will allow for initial storage of the volume to be dredged. First, determine the maximum height at which the material can be placed using the following equation:

$$H_{dm(max)} = D - H_{pd} - H_{fb} \tag{B6}$$

where

$H_{dm\ (max)}$ = maximum height at which dredged material can be placed, ft

D = maximum allowable dike height due to foundation conditions, ft

H_{fb} = freeboard (minimum of 2 ft can be assumed)

Compute the minimum surface area that could be used to store the material:

$$Ad_{(min)} = \frac{V}{Hd_{m(max)}} \tag{B7}$$

If $Ad_{(min)}$ is less than the available surface area, then adequate volumetric storage is available at the site.

Calculation of Minimum Surface Area for Effective Zone Settling

13. If the sediment slurry exhibited zone settling behavior at the expected inflow concentration, the zone settling test results are used to calculate a minimum required ponded surface area in the containment area for effective zone settling to occur. The method is generally applicable to dredged material from a saltwater environment, but the method can also be used for dredged material from freshwater sites if the laboratory settling tests indicate that zone settling occurs in the initial settling process. Additional calculations using flocculent settling data for the solids remaining in

the ponded supernatant water are required for designing the containment area to meet a specific effluent quality standard for suspended solids concentration.

Analyze laboratory data

14. A series of zone settling tests must be conducted as described in Appendix A. The results of the settling tests are analyzed to determine zone settling velocities at the various suspended solids concentrations. The procedure is as follows:

a. Develop a settling curve for each test (as in Figure A1).

b. Calculate the zone settling velocity v_s as the slope of the constant velocity settling (straight-line) portion of the curve. The velocity should be in feet per hour.

c. Plot v_s versus the suspended solids concentration on a semi-log plot as shown in Figure A3. These points should form a straight line. Outliers of higher concentrations are indications of compression settling behavior and should not be included in developing the plot.

d. Use the plot developed in c to develop a curve of solids loading versus solids concentration, as shown in Figure B4. Examples are shown in Appendix D. The solids loading curve should be constructed to a concentration value along the abcissa equal to C_d .

Compute area required for zone settling

15. The minimum surface area determined according to the following steps should provide removal of fine-grained sediments such that suspended solids levels in the effluent do not exceed several hundred milligrams per liter. The area is required for the zone settling process to concentrate the dredged material to the design concentration. The area is computed as follows:

a. Compute the maximum design solids loading $S_{d(max)} = C_i v_s$, where v_s is the zone settling velocity at a concentration equal to C_i from the curve of settling velocity versus concentration (as in Figure A3).

b. Use the design solids concentration C_d as determined in paragraph 11e and construct an operating line from C_d on the x axis tangent to the loading curve as shown in Figure B5. The design loading is obtained on the y axis as S_d . If no tangent can be graphically constructed because of the value of C_d and the shape of the solids loading curve, zone settling will not be a controlling factor and $S_d = S_{d(max)}$.

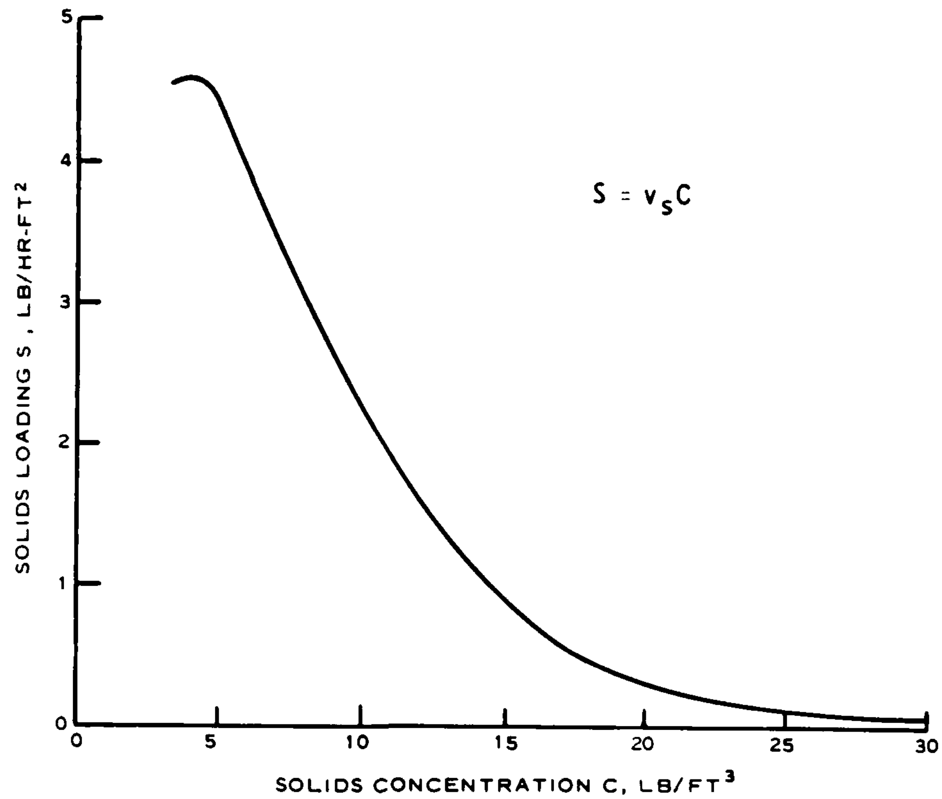

Figure B4. Conceptual solids loading curve for dredged material

c. Compute area requirements as

$$A = \frac{Q_i C_i}{S_d} \tag{B8}$$

where

A = containment surface area requirement, ft^2

Q_i = influent rate, ft^3/hr ($Q_i = A_p V_d$; assume $V_d = 15$ fps in absence of data and convert Q_i calculated in cfs to ft^3/hr)

A_p = cross-sectional area of dredge discharge pipe, ft^2

V_d = velocity of discharge from dredge discharge pipe, fps

C_i = influent solids concentration, lb/ft^3 (150 g/ℓ or 94 lb/ft^3 if no data are available)

S_d = design solids loading, $lb/hr\text{-}ft^2$

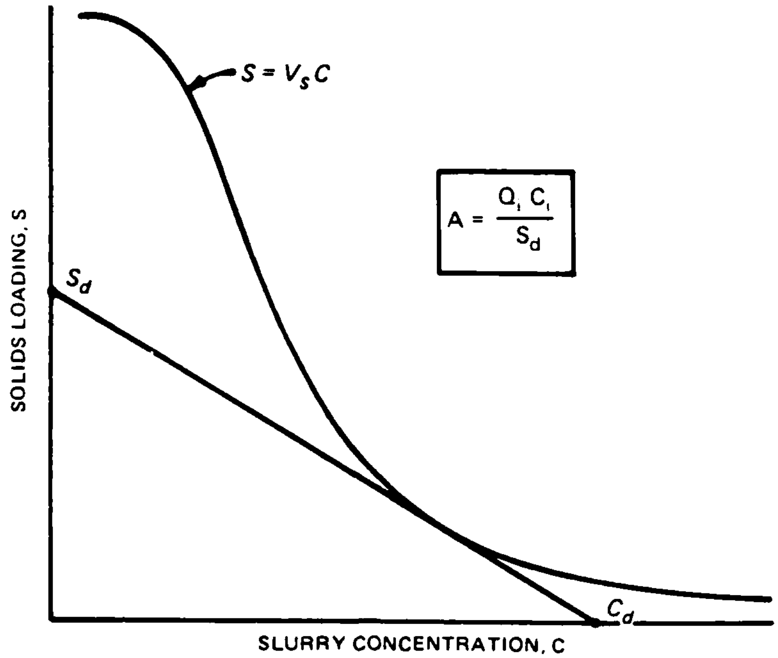

Figure B5. Solids loading curve showing design line

d. Multiply the area calculated by Equation B8 by a hydraulic efficiency correction factor, HECF, to compensate for containment area inefficiencies

$$A_d = (HECF)\ A \qquad (B9)$$

where

A_d = design basin surface area, ft^2

HECF = hydraulic efficiency correction factor (determined as described on page B20)

A = area determined from Equation B8, ft^2

Calculation of Required Retention Time for Flocculent Settling

16. Sediments dredged from a freshwater environment normally exhibit flocculent settling behavior. However, in some cases, the concentration of dredged material slurry is sufficiently high that zone settling will occur. The method of settling can be determined from the laboratory tests.

17. Sediments in a dredged material containment area are comprised of a broad range of particle floc sizes and surface characteristics. In the containment area, larger particle flocs settle at faster rates, thus overtaking finer flocs in their descent. This contact increases the floc sizes and enhances settling rates. The greater the ponding depth in the containment area, the greater is the opportunity for contact among sediments and flocs. Therefore, sedimentation of freshwater dredged material sediments is dependent on the ponding depth and the retention time as well as the properties of the particles.

18. Evaluation of the sedimentation characteristics of a freshwater sediment slurry is accomplished as discussed in Appendix A. The design steps to determine the required retention time for a desired effluent quality are as follows:

a. Calculate the removal percentage at various depths for various times using the concentration profile plot as shown in Figure A2. As an example, the removal percentage for depth D_2 and time T_2 is computed as follows:

$$R = \frac{\text{Area to right of profile}}{\text{Total area}}(100) = \frac{\text{Area } 0, 1, 2, 3, 0^*}{\text{Area } 0, 1, 2, 4, 0}(100) \qquad \text{(B10)}$$

where R is the removal percentage. Determine these areas using a planimeter or by direct graphical measurements and calculations. This approach is used to calculate removal percentages for each depth as a function of time. The depths used should cover the range of ponding depths expected in the containment area. This report recommends a minimum of 2 ft of ponding depth.

b. Plot the solids removal percentages versus time for various ponding depths (withdrawal depths), as shown in Figure B6.

c. Required mean retention times can be selected from Figure B6 for various desired solids removal percentages. Select the retention time T_d that gives the desired removal percentage for the design ponding depth.

d. Note that for the case of flocculent settling of the entire slurry mass, the solids will be removed by gravity sedimentation to a level of 1 to 2 g/ℓ. For this case, the selection of a required retention time for a percentage removal is more

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* These numbers correspond to the numbers used in Figure A2 to indicate the area boundaries for the total area down to depth D_2 and the area to the right of the line for T_2 .

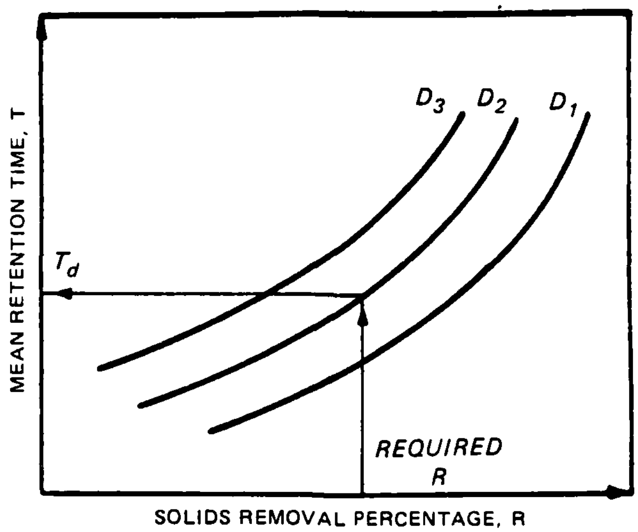

Figure B6. Conceptual plot of solids removal versus time for slurries exhibiting flocculent settling

convenient. For the case of flocculent settling in the supernatant water, where the slurry mass is undergoing zone settling, selection of a required retention time for an effluent suspended solids standard is more appropriate.

Calculation of Required Retention Time for Flocculent Settling in Supernatant Water

Data analysis

19. For slurries exhibiting zone settling, flocculent settling behavior occurs in the supernatant water above the interface. Therefore, a flocculent settling data analysis procedure as outlined in the following paragraphs is required. The steps in the data analysis are as follows:

a. Use the concentration profile diagram as shown in Figure A2 to graphically determine percentages removed, R , for the various time intervals for various ponding depths. This is done by graphically determining the area to the right of each concentration profile and its ratio to the total area above the depth selected, as described for the case of flocculent settling above.

$$R = \frac{\text{Area to right of profile}}{\text{Total area}} (100) \tag{B11}$$

b. Compute the percentage remaining as follows:

$$P = 100 - R \tag{B12}$$

c. Compute values for the average suspended solids concentration remaining in the supernatant at each time of extraction SS as follows:

$$SS_t = \frac{P_t \; SS_o}{100} \tag{B13}$$

where

P_T = percent suspended solids remaining

SS_o = initial suspended solids concentration in the supernatant

d. Tabulate the data, and plot a relationship for suspended solids concentration remaining versus time, using the value for each time of extraction, as shown in Figure B7. An exponential curve fitted through the data points is recommended.

e. By repeating steps a through d, a family of curves showing suspended solids versus retention time for each of several ponding depths may be developed. These curves may be used to determine the required retention time to meet a standard for effluent suspended solids concentrations under good settling conditions for a given estimated ponding depth. For a given ponding depth, simply enter the appropriate curve with the desired maximum effluent suspended solids concentration, and read from the X axis the value of mean field retention time required T_d as predicted by the column test, for that ponding depth. Guidance for adjusting the required retention time

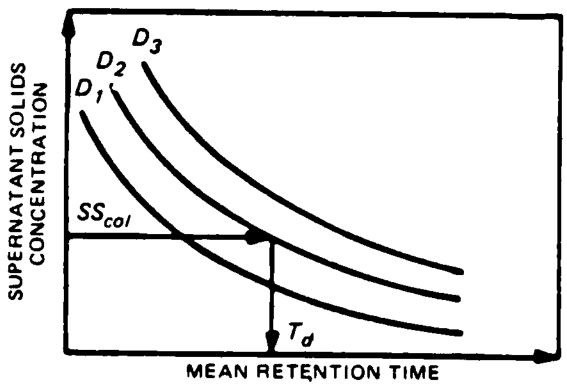

Figure B7. Conceptual plot of supernatant suspended solids concentration versus time from column settling test

value derived from the column test for anticipated resuspension and for estimated hydraulic efficiency is given in the next two sections.

Determination of Retention Time to Meet an Effluent Suspended Solids Concentration

20. The relationship of supernatant suspended solids concentration versus time developed from the column settling test is based on quiescent settling conditions found in the laboratory. The anticipated retention time in an existing disposal area under consideration can be used to determine a predicted effluent suspended solids concentration from the relationship. This predicted value can be considered a minimum value which could be achieved in the field assuming little or no resuspension of settled material. The relationship in Figure B7 can also be used to determine the required retention time to meet a standard for effluent suspended solids. However, an adjustment for anticipated resuspension is appropriate for dredged material exhibiting zone settling. The minimum expected value and the value adjusted for resuspension would provide a range of anticipated suspended solids concentrations in the effluent. The following procedure should be used:

a. The standard for effluent suspended solids SS_{eff} considers anticipated resuspension under field conditions. A corresponding concentration under quiescent laboratory conditions is calculated as

$$SS_{col} = \frac{SS_{eff}}{RF} \qquad \text{(B14)}$$

where

SS_{col} = suspended solids concentration of effluent as estimated from column settling tests

SS_{eff} = suspended solids concentration of effluent considering anticipated resuspension

RF = resuspension factor selected from Table B1

Table B1 summarizes recommended resuspension factors based on comparisons of suspended solids concentrations predicted from column settling tests and field data from a number of sites with varying site conditions. For dredged

Table B1

Recommended Resuspension Factors for the Zone Settling Case for Various Ponded Areas and Depths (After Palermo 1986)

Anticipated Ponded Area	Anticipated Average Ponded Depth	
	less than 2 ft	2 ft or greater
less than 100 acres	2.0	1.5
greater than 100 acres	2.5	2.0

material slurries exhibiting flocculent settling behavior, the concentration of particles in the ponded water is 1 g/ℓ or higher. The resuspension resulting from normal wind conditions will not significantly increase this concentration, therefore an adjustment for resuspension is not required for the flocculent settling case.

b. Using Figure B7 and the anticipated ponding depth, determine the required mean retention time corresponding to SS_{col} .

Estimation of Mean Field and Volumetric or Theoretical Retention Times

21. Estimates of the mean field retention time for expected operational conditions are required for prediction of suspended solids concentrations in the effluent. Estimates of the field retention time must consider the hydraulic efficiency of the disposal area. Mean field retention time T_d can be estimated for given flow rate and ponding conditions by applying a hydraulic efficiency correction factor to the theoretical or volumetric retention time T as follows:

$$T_d = \frac{T_v}{(HECF)} \qquad (B15)$$

The volumetric retention time for a disposal area is calculated as follows:

$$T_v = \frac{V_P}{Q_i}(12.1) = \frac{A_P D_P}{Q_i}(12.1) \qquad (B16)$$

where

T_v = theoretical or volumetric retention time, hr

V_p = volume ponded, acre-ft

A_p = area ponded, acres

D_p = average depth of ponding, ft

Q_i = average inflow rate, cfs

12.1 = conversion factor, acre-ft/cfs to hr

Estimation of Hydraulic Efficiency Correction Factor

22. The hydraulic efficiency correction factor HECF can be estimated by several methods. The most accurate estimate is made possible from dye tracer data previously obtained at the site under operational conditions similar to those for the operation under consideration. In the absence of dye tracer test data or values obtained from other theoretical approaches, the HECF can be assumed based on values obtained by dye tracer studies at similar sites and under similar conditions. Montgomery (1978) recommended a value for HECF of 2.25 based on field studies conducted at several sites. This value should be used for the HECF in the absence of additional data.

Determination of Controlling Factors for Disposal Area Geometry

23. Previous calculations have provided a design surface area A_d and/or a volumetric retention time T_v required for fine-grained dredged material sedimentation and the initial volume required for initial storage V . A ponding depth H_{pd} was also assumed. These values are then used, as described in the following paragraphs, to determine the required disposal area geometry. Throughout the design process, the existing topography of the containment area site must be considered since it can have a significant effect on the resulting geometry of the containment area. Any limitations on dike height should also be determined based on an appropriate geotechnical evaluation.

Surface area requirement for zone settling

24. The following procedure should be used:

a. Estimate the thickness of the dredged material at the end of the disposal operation:

$$H_{dm} = \frac{V}{A_d} \qquad \text{(B17)}$$

where

H_{dm} = thickness of the dredged material layer at the end of the dredging operation, ft

V = volume of dredged material in the basin, ft^3 (from Equation B5)

A_d = design surface area, ft^2 (as determined from Equation B9, or the known surface area for existing sites)

b. Determine the maximum height allowed for confining dikes. This height should be based on appropriate geotechnical design of the dikes.

c. Add the ponding depth and freeboard depth to H_{dm} to determine the required containment area depth D (dike height):

$$D = H_{dm} + H_{pd} + H_{fb} \qquad \text{(B18)}$$

d. Compare this value with the allowable dike height determined in b.

Containment area ponded volume
requirement for flocculent settling

25. The following procedure should be used:

a. Compute the volume required for sedimentation:

$$V_P = Q_i T_v \qquad \text{(B19)}$$

where V_P is the containment area ponded water volume in cubic feet required for meeting effluent suspended solids concentration requirements.

b. Determine the maximum height D allowed for confining dikes. (See previous paragraphs.) In some cases, it might be desirable to use less than the maximum allowed dike height.

c. Compute a minimum for the design area required for storage:

$$A_d = \frac{V}{H_{dm(max)}} \qquad \text{(B20)}$$

where

$$H_{dm(max)} = D - H_{pd} - H_{fb} \tag{B21}$$

or set the design area A_d equal to the known surface area for existing sites.

d. Evaluate the volume available for sedimentation near the end of the disposal operation:

$$V^* = H_{pd}A_d \tag{B22}$$

where V^* is the volume in cubic feet available for sedimentation near the end of the disposal operation.

e. Compare V^* and V_p. If the volume required for sedimentation is larger than V^*, the containment area will not meet the effluent suspended solids concentration requirements for the entire disposal operation. The following three measures can be considered to ensure that effluent requirements are met: (1) increase the design area A_d, (2) operate the dredge on an intermittent basis when V^* becomes less than V_p or use a smaller size dredge, and (3) provide for posttreatment of the effluent to remove the excess suspended solids.

f. Estimate the thickness of dredged material at the end of the disposal operation using Equation B17 with A_d as determined using step c above.

g. Determine the required containment area depth using Equation B18 and the results from step f above.

h. Compare this depth with the maximum allowable dike height.

i. If the maximum dike height allowed by foundation conditions is less than the containment area depth requirement determined from Equation B18, the design area A_d must be increased until the depth requirement can be accommodated by the allowable dike height; the thickness of the dredged material layer must also be decreased if A_d is increased.

APPENDIX C: EXAMPLE ADDAMS INPUT AND OUTPUT

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OLD,ADDAMS
/-ADDAMS
 ENTER DATA FILE NAME OR RETURN FOR NEW DATA FILE
? WTGSETD
 DEVICE-
? ALP


  WELCOME TO THE ADDAMS FAMILY OF DREDGING PROGRAMS
  VERSION  0 OF 1 APRIL 1985

  ADDAMS EXECUTIVE COMMAND?
? I SETT 3
  'SETTLE' INPUT ROUTINE
 DATA SET #    3 - HART MILLER (53.6 G/L - 1984)

 ENTER A NEW TITLE FOR THIS RUN OR HIT 'RETURN'
 FOR EXISTING TITLE.

?
                          SETTLE INPUT MENU

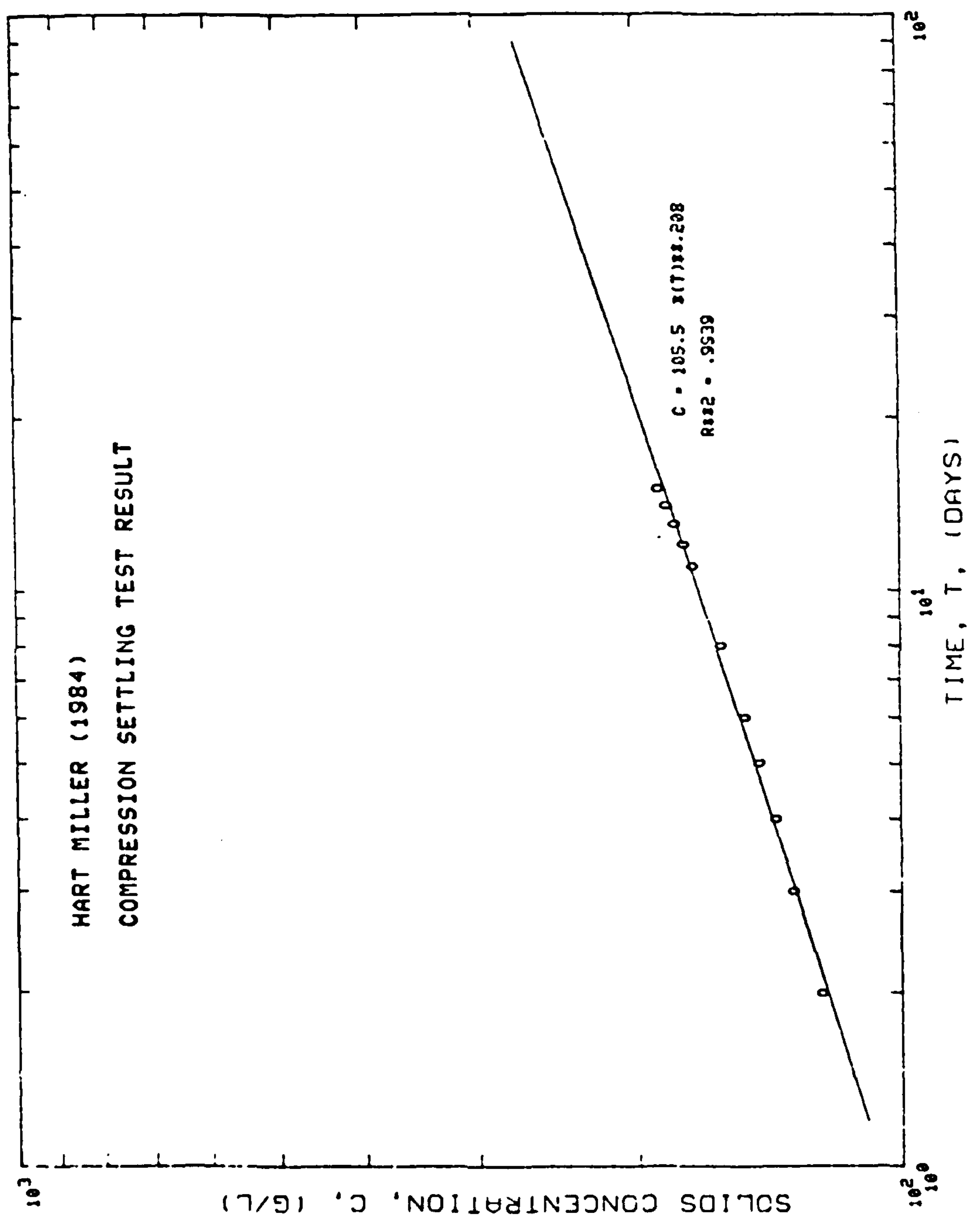
          KEYWORD                OPERATION
          =======   ========================================
           COMP     ENTER THE COMPRESSION SETTLING TEST SUBROUTINE
           FLOC     ENTER THE FLOCCULENT SETTLING TEST SUBROUTINE
           ZONE     ENTER THE ZONE SETTLING TEST SUBROUTINE
           PROJ     ENTER THE PROJECT DATA SUBROUTINE
           STAT     STATUS OF INPUT DATA REQUIRED FOR RUN
           RUN      GO DIRECTLY TO EXECUTION AND OUTPUT ROUTINES
           END      END  THE SETT INPUT ROUTINE
INPUT THE APPROPRIATE KEYWORD FOR THE DESIRED OPERATION:
? COMP
 THE FOLLOWING DATA FOR THE COMPRESSION SETTLING TEST HAVE BEEN ENTERED:
    ============================================================
       LINE NUMBER      TIME,DAYS      AVERAGE CONCENTRATION,G/L
    ------------------------------------------------------------
             1             2.00                124.00
             2             3.00                133.50
             3             4.00                139.60
             4             5.00                145.70
             5             6.00                151.20
             6             8.00                160.90
             7            11.00                172.70
             8            12.00                176.60
             9            13.00                180.70
            10            14.00                184.60
            11            15.00                188.20
    ============================================================
 DO YOU WISH TO MAKE ANY CHANGES TO THIS DATA LISTING(YES OR NO)?
? NO
  CURVE FITTING FOR X=TIME AND Y=CONCENTRATION:


 THE FOLLOWING RESULTS FOR THE 15DAY TEST DATA
 WERE OBTAINED BY LEAST SQUARES CURVE FIT.
 THE EQUATION FOR THE FITTED CURVE IS:Y =  105.5    * X **  .2080
 THE COEFFICIENT OF DETERMINATION (R**2) IS       .99
```

TABLE OF DATA POINTS,STATISTICALLY FITTED POINTS: AND %ERROR

POINTS	X	Y	Y-FITTED	%ERROR
1	2.00	124.00	121.90	-1.69
2	3.00	133.50	132.63	-.65
3	4.00	139.60	140.81	.87
4	5.00	145.70	147.50	1.24
5	6.00	151.20	153.20	1.32
6	8.00	160.90	162.65	1.09
7	11.00	172.70	173.79	.63
8	12.00	176.60	176.96	.20
9	13.00	180.70	179.93	-.43
10	14.00	184.60	182.73	-1.01
11	15.00	188.20	185.37	-1.50

WOULD YOU LIKE TO HAVE THE DATA AND LINE PLOTTED(YES OR NO)?
? YES
HIT RETURN WHEN READY TO CONTINUE



HART MILLER (1984)
COMPRESSION SETTLING TEST RESULT
C = 105.5 *(T)**.208
R**2 = .9539
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)
10^0
10^1
10^2
10^2
10^3

SETTLE INPUT MENU

KEYWORD	OPERATION
COMP	ENTER THE COMPRESSION SETTLING TEST SUBROUTINE
FLOC	ENTER THE FLOCCULENT SETTLING TEST SUBROUTINE
ZONE	ENTER THE ZONE SETTLING TEST SUBROUTINE
PROJ	ENTER THE PROJECT DATA SUBROUTINE
STAT	STATUS OF INPUT DATA REQUIRED FOR RUN
RUN	GO DIRECTLY TO EXECUTION AND OUTPUT ROUTINES
END	END THE SETT INPUT ROUTINE

INPUT THE APPROPRIATE KEYWORD FOR THE DESIRED OPERATION:
? FLOC
OBSERVED FLOCCULENT SETTLING CONCENTRATIONS, MG/L,WITH DEPTH

TIME	DEPTH FROM TOP OF SETTLING COLUMN,FT.								
HOURS	.11	.41	.76	1.11	1.46	1.76	2.11	2.46	2.76
.0	746.10	746.10	.00	.00	.00	.00	.00	.00	.00
.7	288.00	372.40	.00	.00	.00	.00	.00	.00	.00
.8	276.80	402.40	468.00	.00	.00	.00	.00	.00	.00
2.0	266.80	350.80	387.20	414.80	.00	.00	.00	.00	.00
3.0	237.20	353.80	344.00	366.40	646.70	438.80	485.60	.00	.00
4.0	263.20	341.60	325.20	334.00	361.60	350.40	360.00	348.00	338.80
6.0	.00	214.00	239.60	248.40	251.20	275.60	252.00	273.60	264.00
12.0	.00	118.80	.00	126.80	.00	150.40	.00	130.40	.00
24.0	.00	69.40	59.00	58.80	78.40	66.90	62.80	65.10	102.80
48.0	.00	.00	39.50	38.50	41.30	39.30	41.00	42.20	48.40
120.0	.00	.00	32.10	28.80	27.80	28.40	29.00	32.00	29.20

WOULD YOU LIKE TO MAKE ANY CHANGES TO THIS DATA SET (YES OR NO)?
? NO
THE CONCENTRATION DATA HAS BEEN CONVERTED TO
FRACTION OF AVERAGE INITIAL CONCENTRATION REMAINING
TO WHAT DEPTH(FT) DO YOU WISH TO ANALYZE THE DATA?
? 3
PERCENT OF INITIAL CONCENTRATION WITH TIME

TIME	DEPTH FROM TOP OF SETTLING COLUMN,FT.								
HOURS	.11	.41	.76	1.11	1.46	1.76	2.11	2.46	2.76
.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
.7	38.60	49.91	.00	.00	.00	.00	.00	.00	.00
.8	37.10	53.93	62.73	.00	.00	.00	.00	.00	.00
2.0	35.76	47.02	51.90	55.60	.00	.00	.00	.00	.00
3.0	31.79	47.42	46.11	49.11	86.68	58.81	65.09	.00	.00
4.0	35.28	45.78	43.59	44.77	48.47	46.96	48.25	46.64	45.41
6.0	.00	28.68	32.11	33.29	33.67	36.94	33.78	36.67	35.38
12.0	.00	15.92	.00	17.00	.00	20.16	.00	17.48	.00
24.0	.00	9.30	7.91	7.88	10.51	8.97	8.42	8.73	13.78
48.0	.00	.00	5.29	5.16	5.54	5.27	5.50	5.66	6.49
120.0	.00	.00	4.30	3.86	3.73	3.81	3.89	4.29	3.91

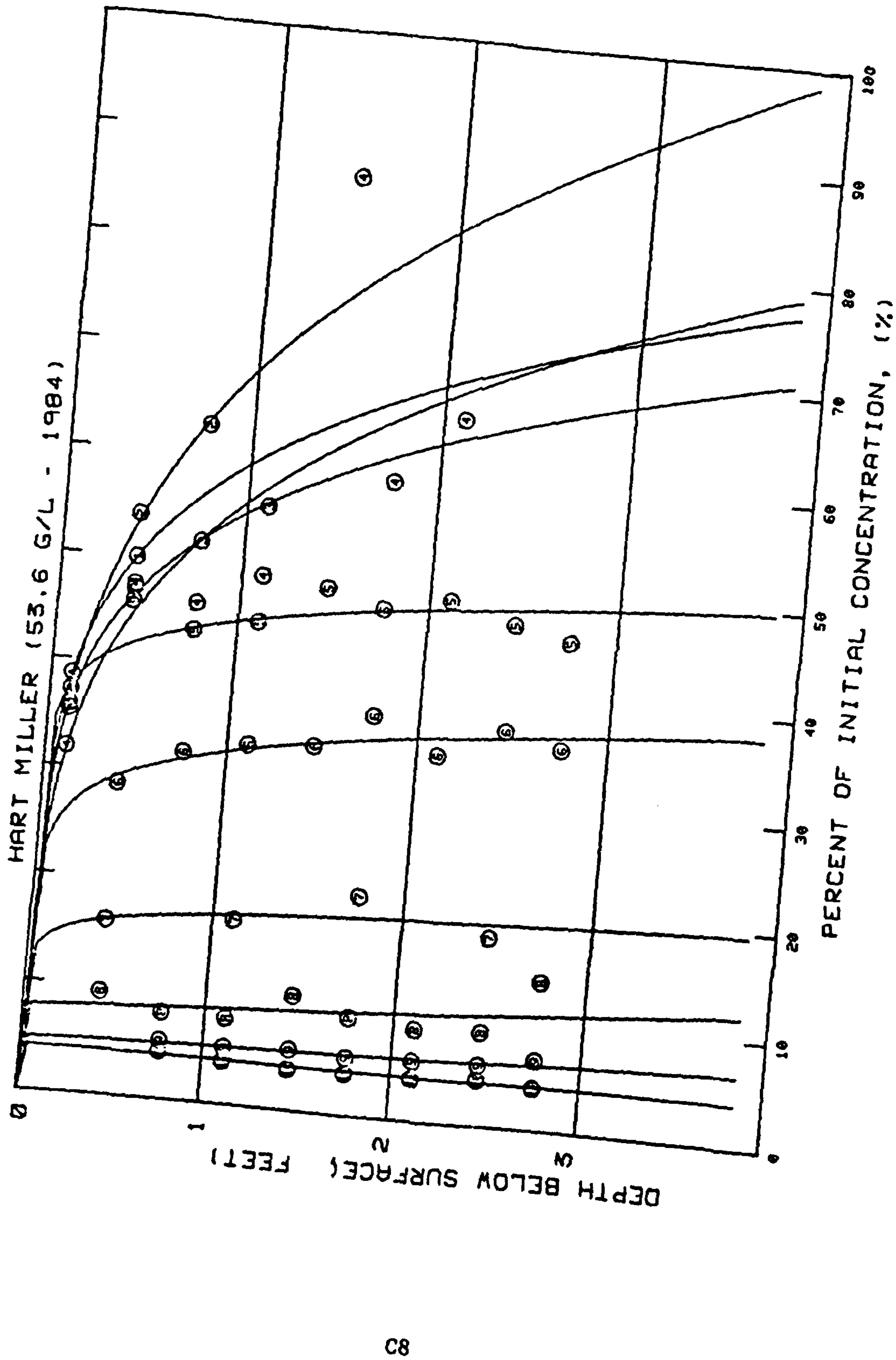
DO YOU WISH TO MAKE ANY CHANGES TO THE DATA LISTING(YES OR NO)?
? NO
THE FOLLOWING TABLE IS A SUMMARY OF THE COEFFICIENTS
OF DETERMINATION FOR THE FLOCCULENT CURVES.

CURVE NO.	TIME,HRS.	POWER CURVE	EXPONENTIAL CURVE
1	.71	1.00	1.00
2	.76	1.00	.92
3	2.00	1.00	.87
4	3.00	.71	.63
5	4.00	.72	.39
6	6.00	.81	.67
7	12.00	.46	.33
8	24.00	.15	.26
9	48.00	.49	.62
10	120.00	.00	.00

. WOULD YOU LIKE TO SEE THE DETAILS OF THE CURVE FITS
FOR ANY TIME INTERVAL (YES OR NO)?
? NO
PLEASE INPUT THE CURVE NUMBERS FOR ANY CURVES YOU WOULD LIKE TO SPECIFY
THE CURVE TYPE WITH THE LOWER R**2 VALUE BE USED.
INPUT "0" IF NONE
? 0

CURVE NO	TIME,HRS	A	B	R**2	CURVE TYPE
1	.71	59.41	.1953	1.000	POWR
2	.76	68.11	.2737	.999	POWR
3	2.00	54.86	.1910	.997	POWR
4	3.00	55.87	.2567	.713	POWR
5	4.00	44.71	.7871E-01	.720	POWR
6	6.00	32.52	.1135	.814	POWR
7	12.00	17.32	.8632E-01	.457	POWR
8	24.00	7.727	.1146	.262	EXPO
9	48.00	4.778	.8364E-01	.623	EXPO
10	120.00	4.007	0.	.000	POWR

WOULD YOU LIKE TO CHANGE OR DELETE ANY OF THESE CURVES (YES OR NO)?
? NO
WOULD YOU LIKE TO HAVE THE DATA AND CURVES PLOTTED (YES OR NO)?
? YES
HIT RETURN WHEN READY TO CONTINUE


HART MILLER (53.6 G/L - 1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE(FEET)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100

```
 WOULD YOU LIKE TO  CHANGE OR DELETE ANY OF THESE CURVES (YES OR NO)?
? NO
 ENTER THE PONDING DEPTHS FOR WHICH YOU WISH TO HAVE
THE REMOVAL PERCENTAGES  CALCULATED.
 A MINIMUM OF 3 DEPTHS MUST BE SPECIFIED.
? 1 2 2.5
                REMOVAL VERSUS TIME AND DEPTH
```

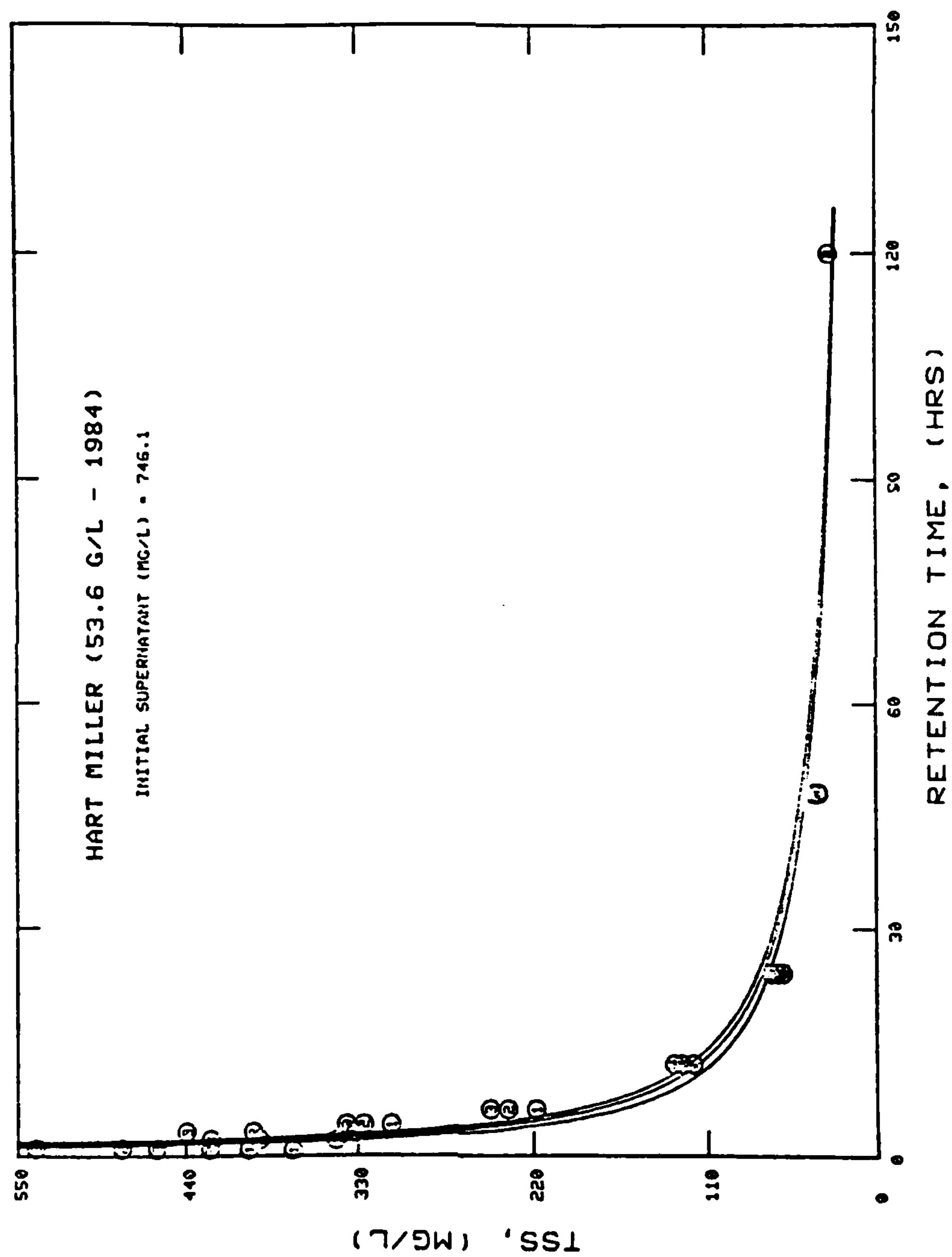
TIME,HRS	1.00FT	2.00FT	2.50FT
.71	50.30	43.09	40.56
.76	46.53	35.35	31.28
2.00	53.94	47.42	45.13
3.00	55.55	46.89	43.76
4.00	58.55	56.23	55.45
6.00	70.79	68.40	67.59
12.00	84.06	83.08	82.75
24.00	91.81	91.32	91.05
48.00	95.02	94.80	94.69
120.00	95.99	95.99	95.99

```
  CURVE FITTING FOR Y=TIME AND X=100-%REMOVAL


     REGRESSION COEFFICIENTS FOR %REMOVAL VS. TIME CURVES
```

CURVE NO	DEPTH,FT	A	B	R**2
1	1.00	922.3	-1.627	.920
2	2.00	858.1	-1.556	.929
3	2.50	850.0	-1.538	.932

```
  WOULD YOU LIKE TO SEE THE DETAILS OF THE CURVE FITS
 FOR ANY TIME INTERVAL (YES OR NO)?
? NO
 WOULD YOU LIKE TO HAVE THE DATA AND CURVES PLOTTED (YES OR NO)?
? YES
 HIT RETURN WHEN READY TO CONTINUE
```


HART MILLER (53.6 G/L - 1984)
INITIAL SUPERNATANT (MG/L) = 746.1
TSS, (MG/L)
RETENTION TIME, (HRS)
0
110
220
330
440
550
30
60
90
120
150

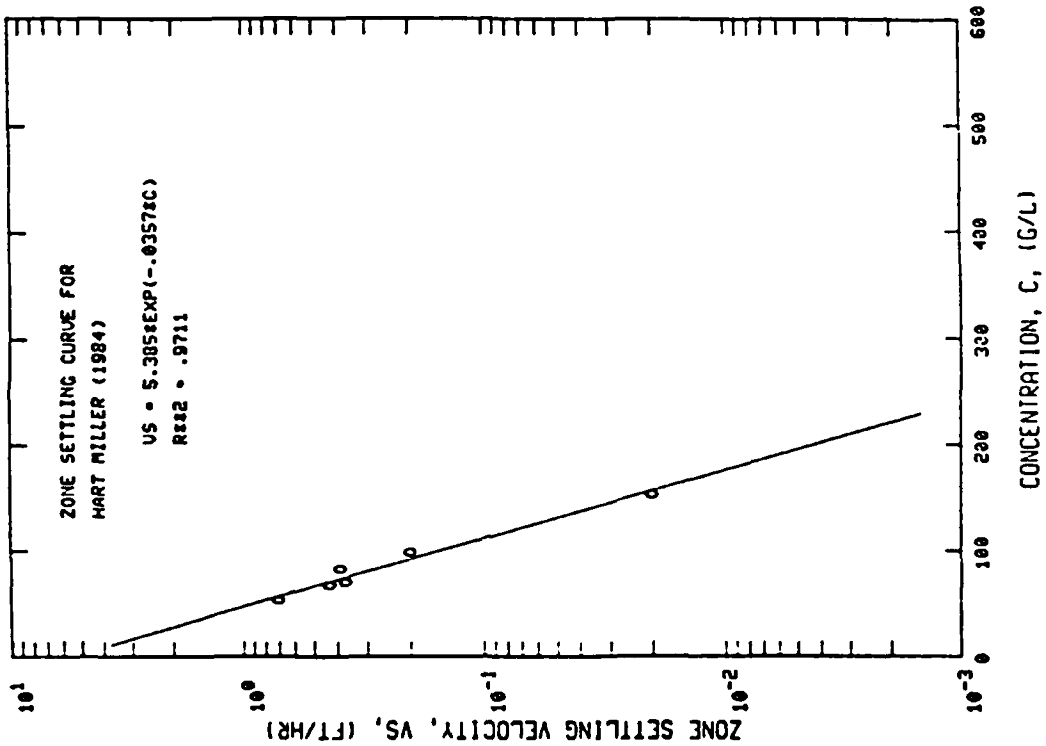
```
 WOULD YOU LIKE TO MAKE ANY CHANGES TO THE DATA(YES OR NO)?
? NO
                          SETTLE INPUT MENU

         KEYWORD                  OPERATION
         =======    ========================================
          COMP      ENTER THE COMPRESSION SETTLING TEST SUBROUTINE
          FLOC      ENTER THE FLOCCULENT SETTLING TEST SUBROUTINE
          ZONE      ENTER THE ZONE SETTLING TEST SUBROUTINE
          PROJ      ENTER THE PROJECT DATA SUBROUTINE
          STAT      STATUS OF INPUT DATA REQUIRED FOR RUN
          RUN       GO DIRECTLY TO EXECUTION AND OUTPUT ROUTINES
          END       END  THE SETT INPUT ROUTINE
INPUT THE APPROPRIATE KEYWORD FOR THE DESIRED OPERATION:
? ZONE
 ============================================================
 LINE NO.   CONCENTRATION,G/L   ZONE SETTLING VELOCITY,FT/HR
 ------------------------------------------------------------
      1              53.60                         .710
      2              67.50                         .430
      3              70.00                         .370
      4              82.80                         .390
      5              98.00                         .200
      6             152.30                         .020
 ============================================================
  DO YOU WISH TO MAKE ANY CHANGES TO THE DATA SET (YES OR NO)?
? NO
  CURVE FITTING FOR X=CONCENTRATION AND Y=ZONE SETTLING VELOCITY:

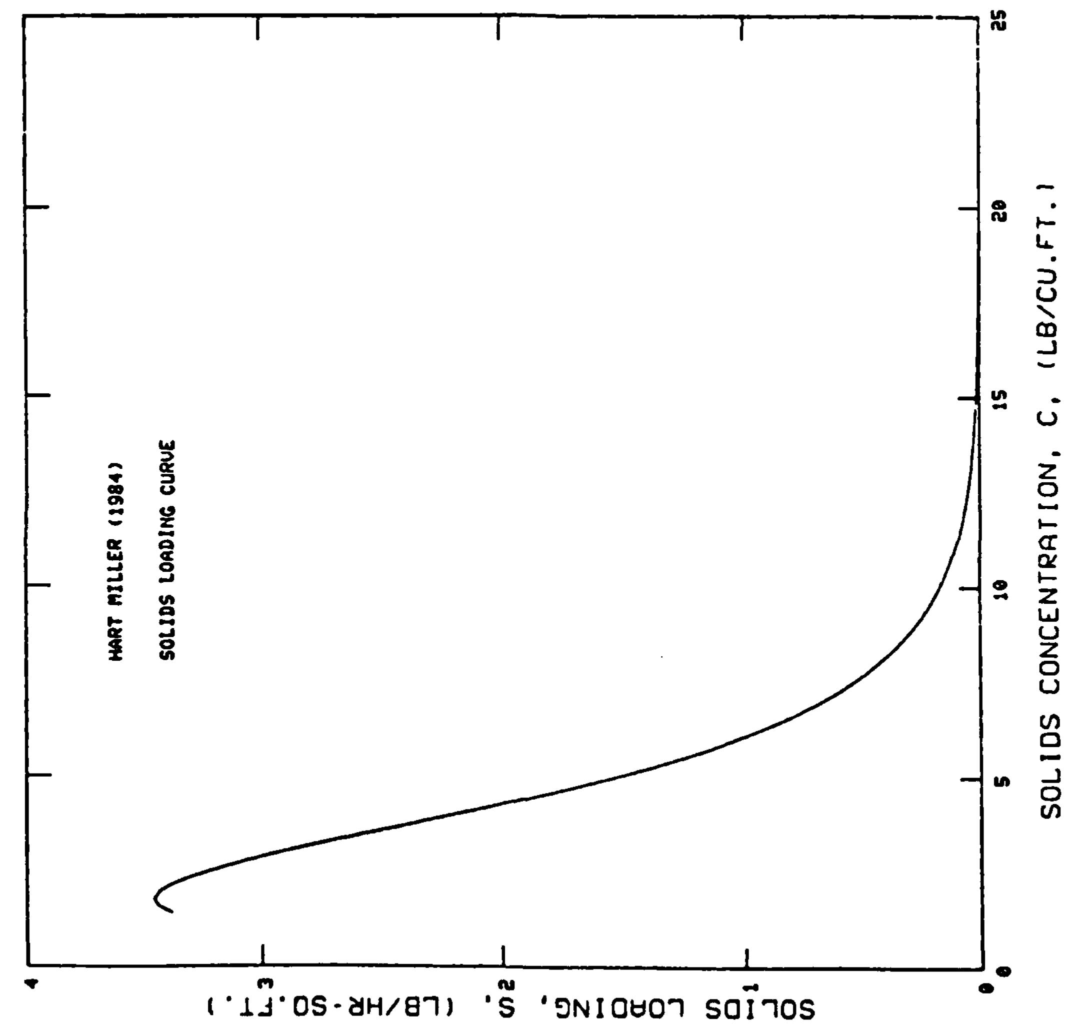

 THE FOLLOWING RESULTS FOR THE  SETTLING  DATA
 WERE OBTAINED BY LEAST SQUARES CURVE FIT.
      THE EQUATION FOR THE FITTED CURVE IS: Y= 5.385    *EXP ( -.3576E-01 * X)
 THE COEFFICIENT OF DETERMINATION (R**2) IS       .97


 TABLE OF DATA POINTS,STATISTICALLY FITTED POINTS, AND %ERROR


    POINTS     X             Y             Y-FITTED       %ERROR
      1      53.60          .71              .79           11.55
      2      67.50          .43              .48           12.05
      3      70.00          .37              .44           19.08
      4      82.80          .39              .28          -28.52
      5      98.00          .20              .16          -19.06
      6     152.30          .02              .02           16.11
   WOULD YOU LIKE THESE DATA & LINE PLOTTED(YES OR NO)?
 ? YES
  HIT RETURN WHEN READY TO CONTINUE
```


ZONE SETTLING CURVE FOR
HART MILLER (1984)
VS = 5.385*EXP(-.0357*C)
R**2 = .9711
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

```
  DO YOU WISH TO MAKE ANY CHANGES TO THE DATA SET (YES OR NO)?
? NO
  PLEASE TYPE:
      'PRINT' IF YOU DESIRE A TABLE OF SOLIDS LOADING VALUES,
      'PLOT' IF YOU DESIRE A PLOT OF SOLIDS LOADING DATA,OR
      'BOTH'  IF YOU WOULD LIKE BOTH A TABLE AND CORRESPONDING PLOT.
? BOTH
      ===============================================
      SUSPENDED SOLIDS     ZONE SETTLING         SOLIDS
        CONCENTRATION         VELOCITY          LOADING
         G/L   LB/FT3          FT/HR           LB/HR-FT2
      -------------------------------------------------
         28.     1.7           1.981              3.46
         80.     5.0            .308              1.54
        160.    10.0            .018               .18
        240.    15.0            .001               .02
        320.    20.0            .000               .00
      ===============================================
  HIT RETURN WHEN READY TO CONTINUE
```


HART MILLER (1984)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
1
2
3
4

```
                      SETTLE INPUT MENU

          KEYWORD                OPERATION
          =======    =========================================
           COMP      ENTER THE COMPRESSION SETTLING TEST SUBROUTINE
           FLOC      ENTER THE FLOCCULENT SETTLING TEST SUBROUTINE
           ZONE      ENTER THE ZONE SETTLING TEST SUBROUTINE
           PROJ      ENTER THE PROJECT DATA SUBROUTINE
           STAT      STATUS OF INPUT DATA REQUIRED FOR RUN
           RUN       GO DIRECTLY TO EXECUTION AND OUTPUT ROUTINES
           END       END  THE SETT INPUT ROUTINE
INPUT THE APPROPRIATE KEYWORD FOR THE DESIRED OPERATION:
? END


  ADDAMS EXECUTIVE COMMAND?
? STOP
```

END
DATE
FILMED
5-88
DTIC

WES TR D-88-2 APPENDIX D: ADDAMS-GENERATED CURVES... 1 of 2

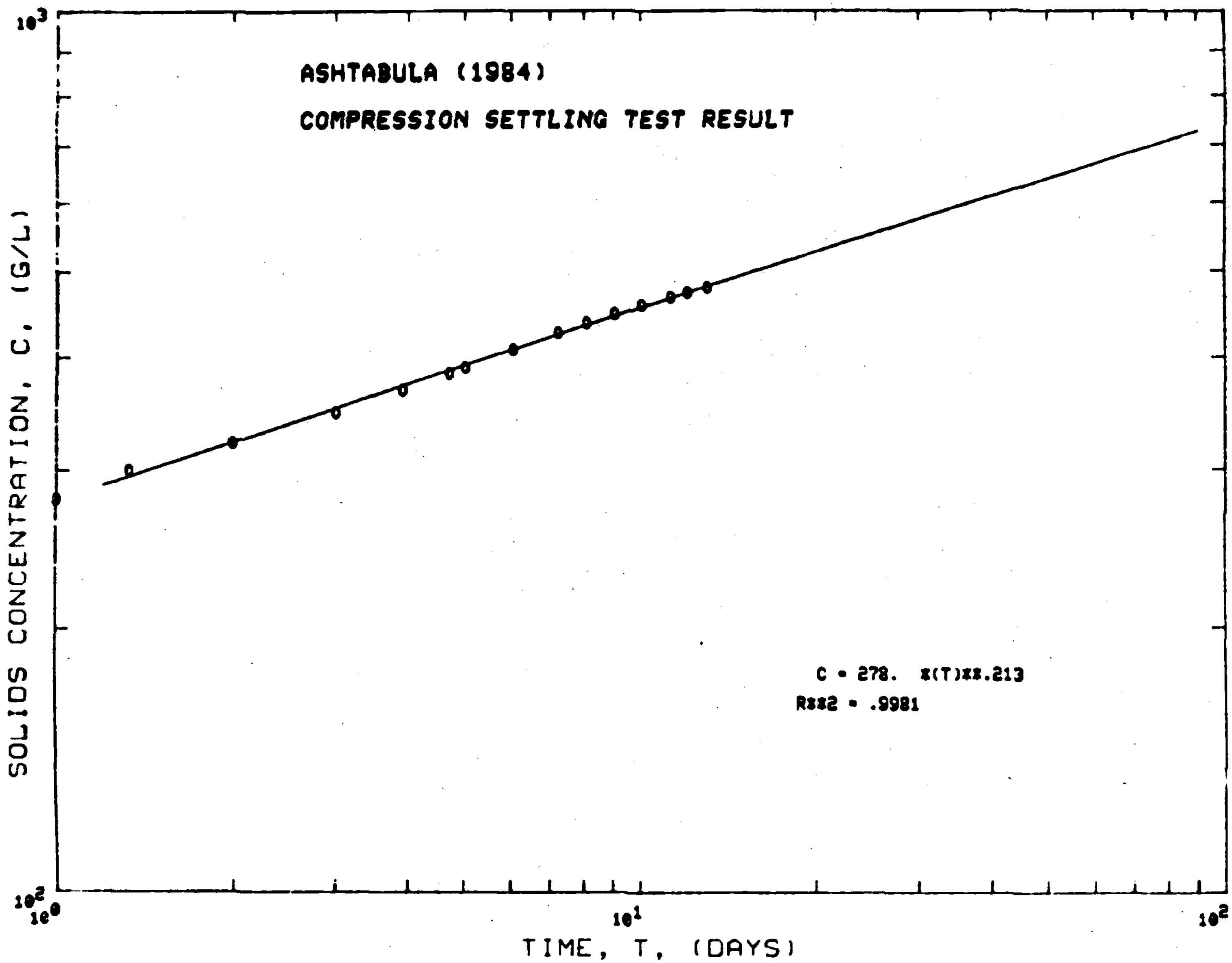
DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

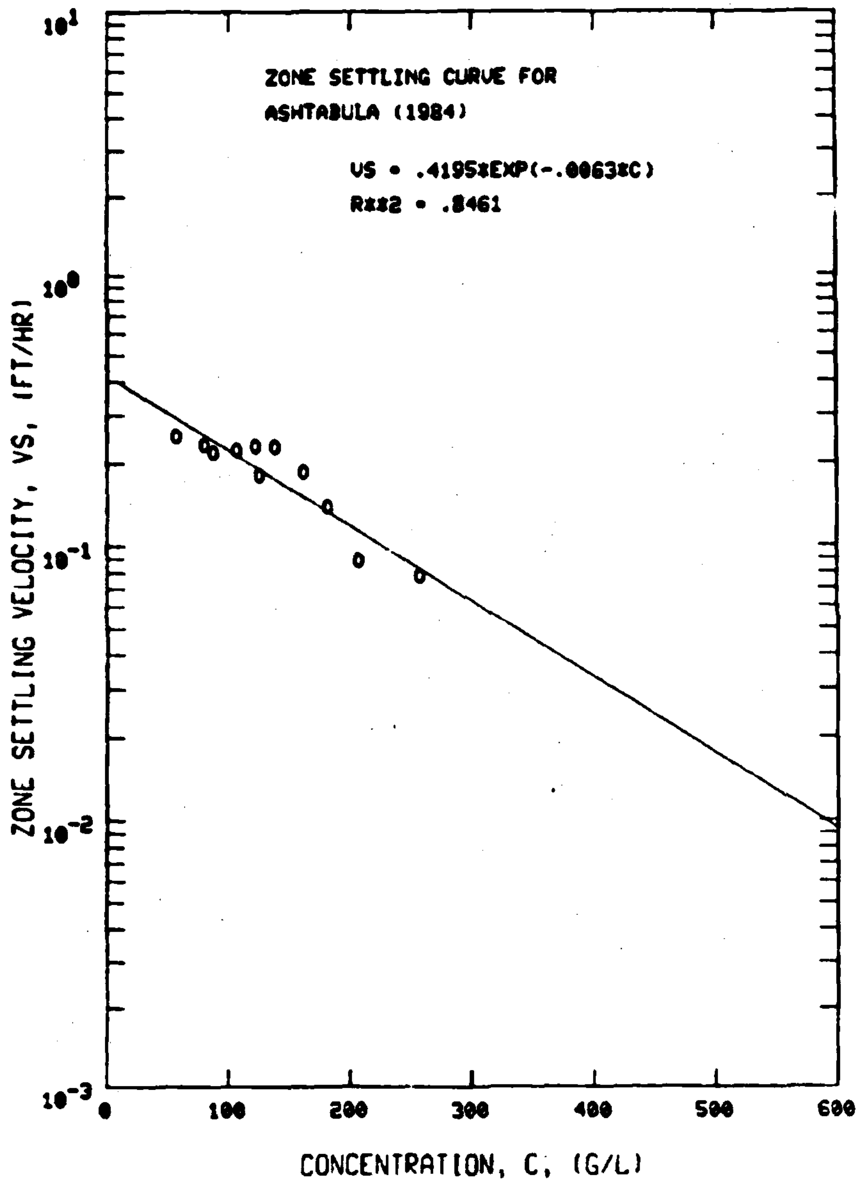
TECHNICAL REPORT D-88-2

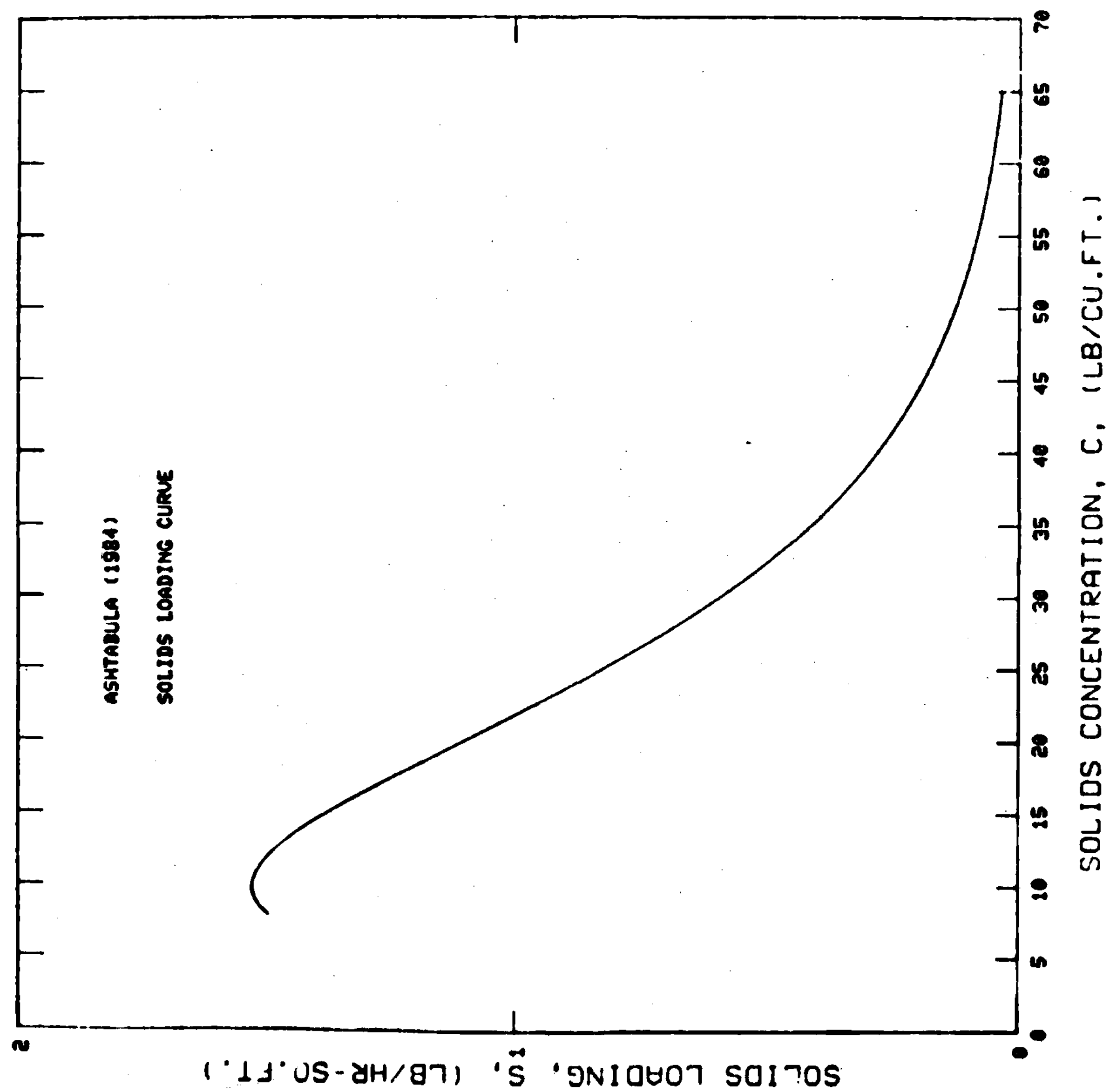
VERIFICATION OF PROCEDURES FOR DESIGNING DREDGED MATERIAL CONTAINMENT AREAS FOR SOLIDS RETENTION

APPENDIX D: ADDAMS-GENERATED CURVES FOR COLUMN SETTLING TESTS

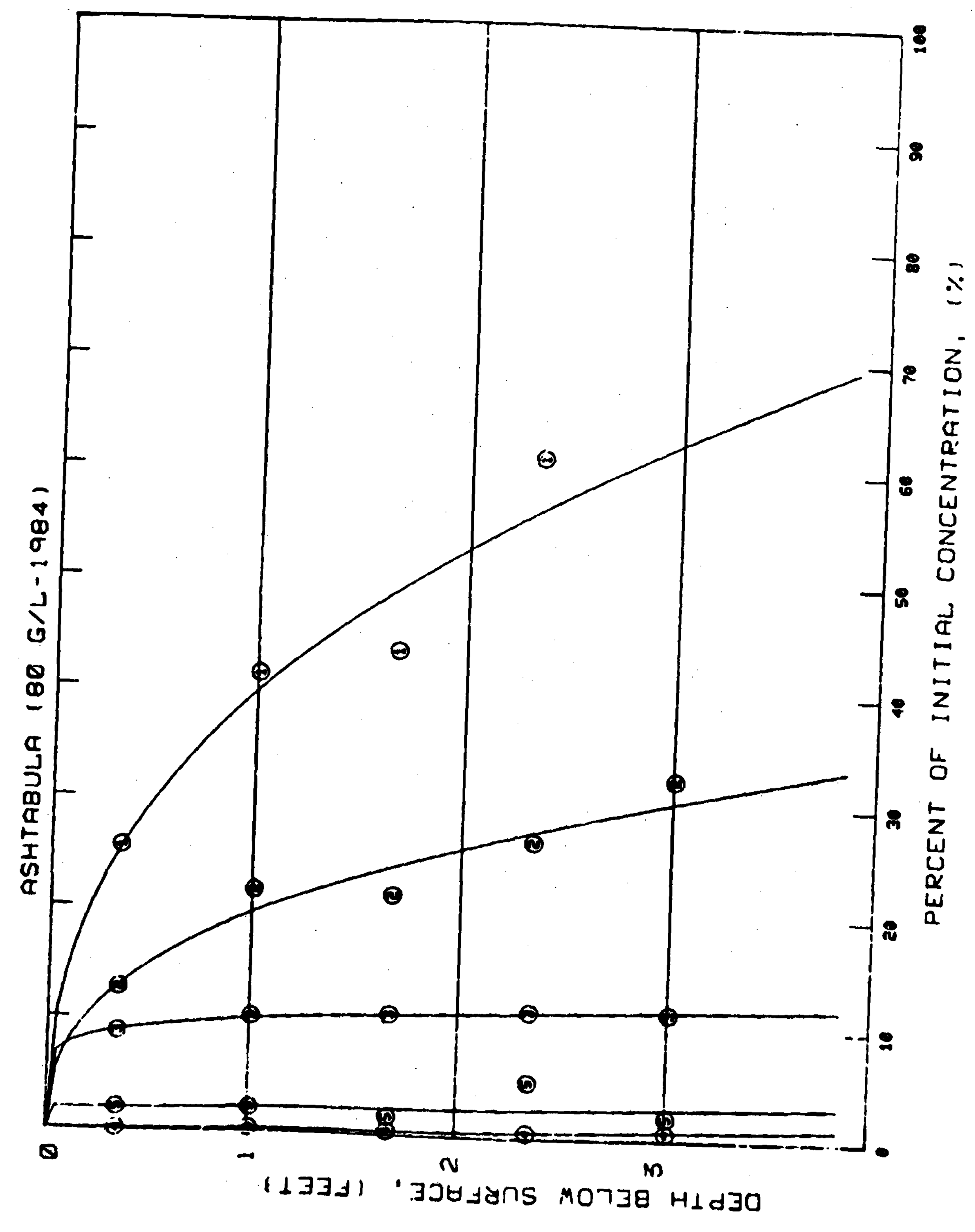
LIST OF FIGURES IN APPENDIX D

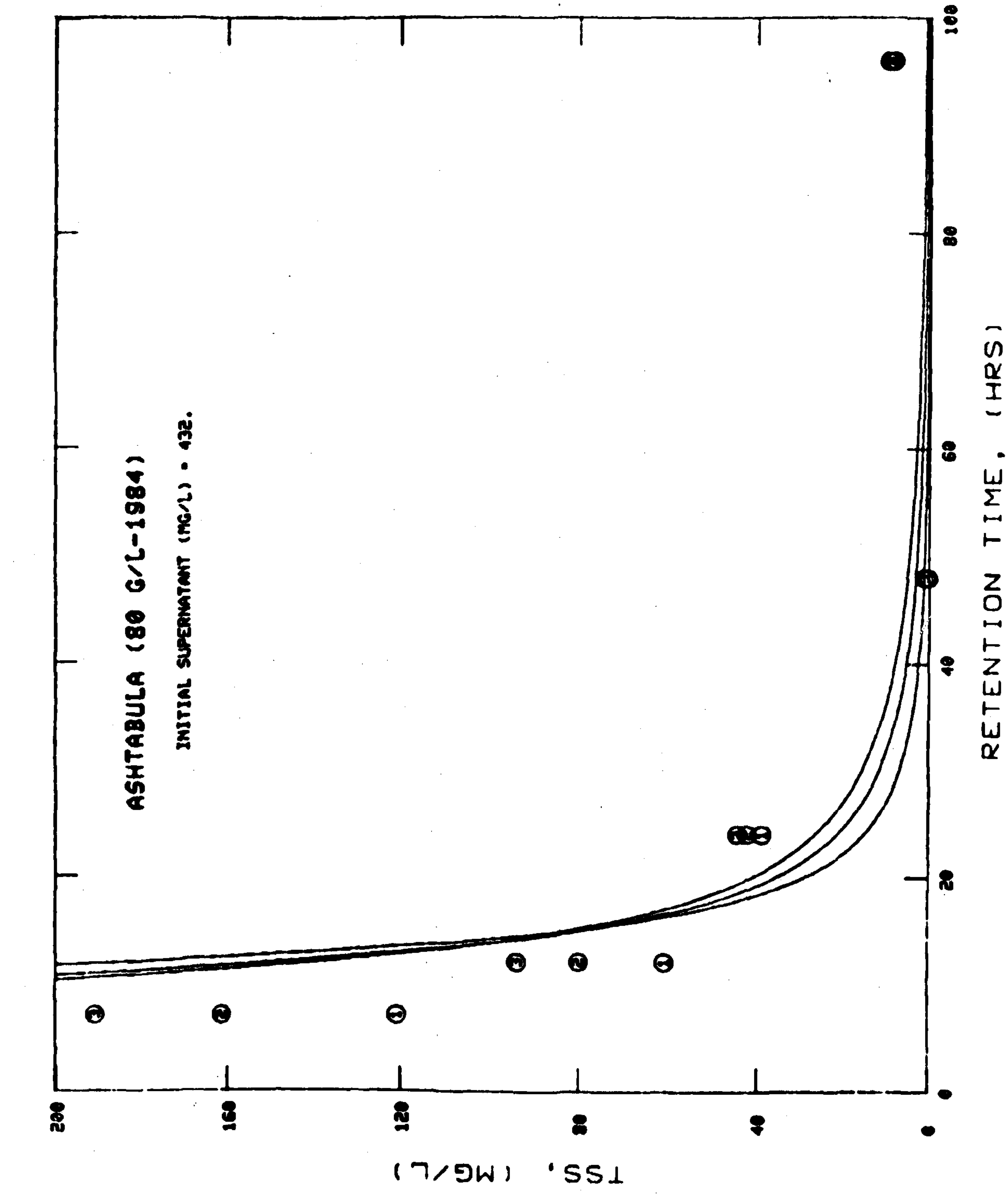

ASHTABULA (1984)
COMPRESSION SETTLING TEST RESULT
C = 278. *(T)**.213
R**2 = .9981
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2

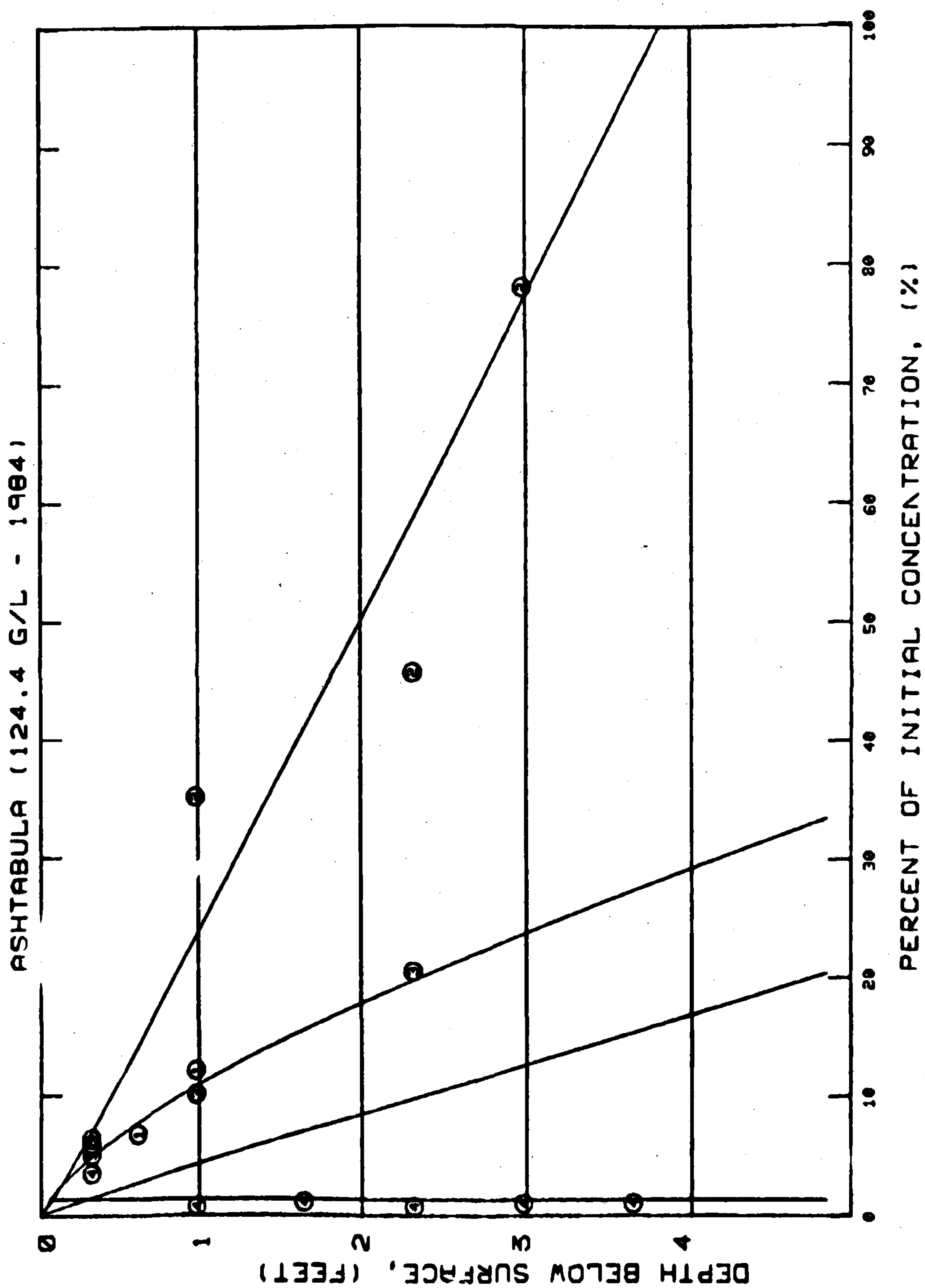

ZONE SETTLING CURVE FOR
ASHTABULA (1984)
VS = .4195*EXP(-.0063*C)
R**2 = .8461
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600



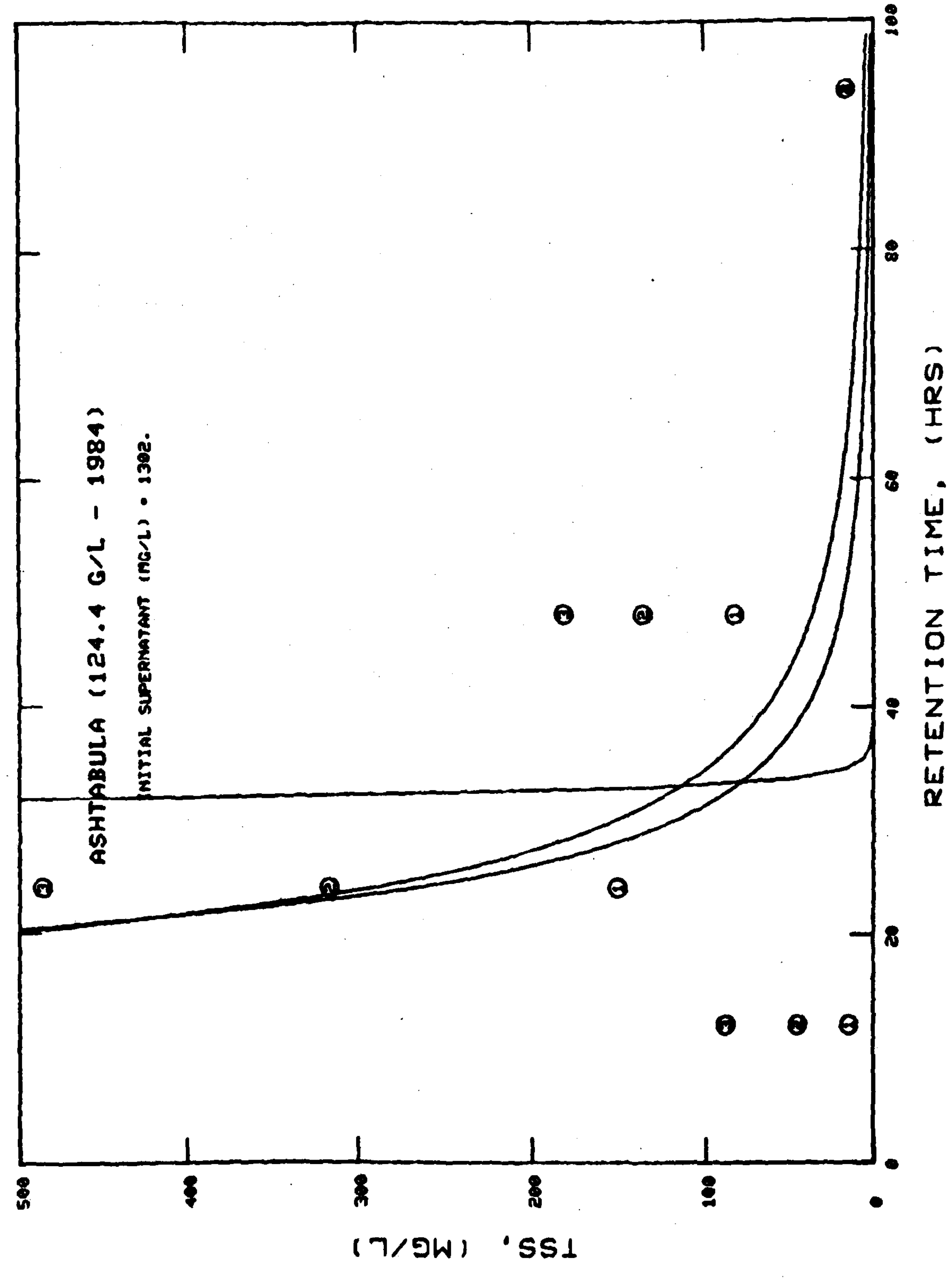
ASHTABULA (1984)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
0
1
2


ASHTABULA (80 G/L-1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100

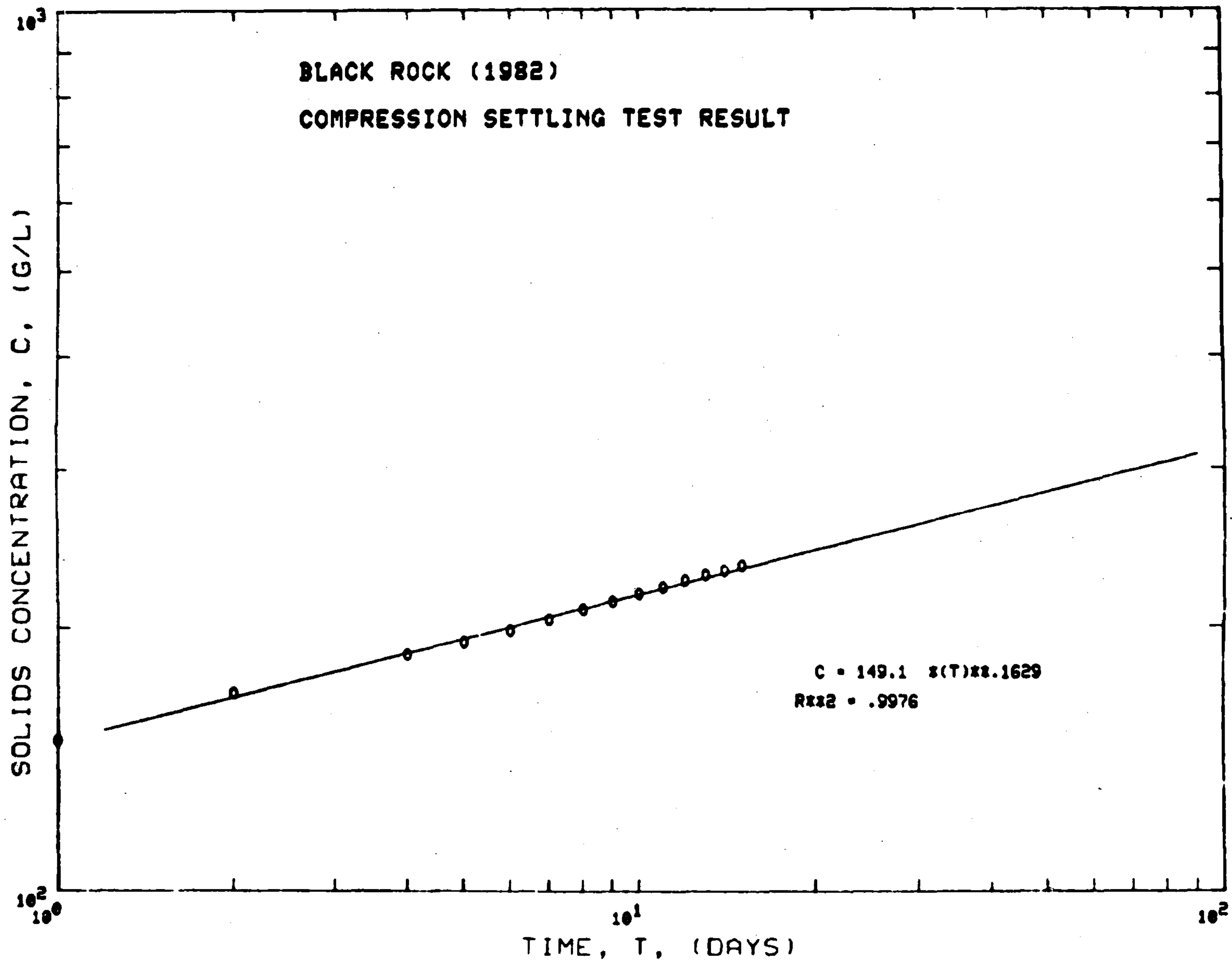

ASHTABULA (80 G/L-1984)
INITIAL SUPERNATANT (MG/L) = 432.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
40
80
120
160
200
0
20
40
60
80
100



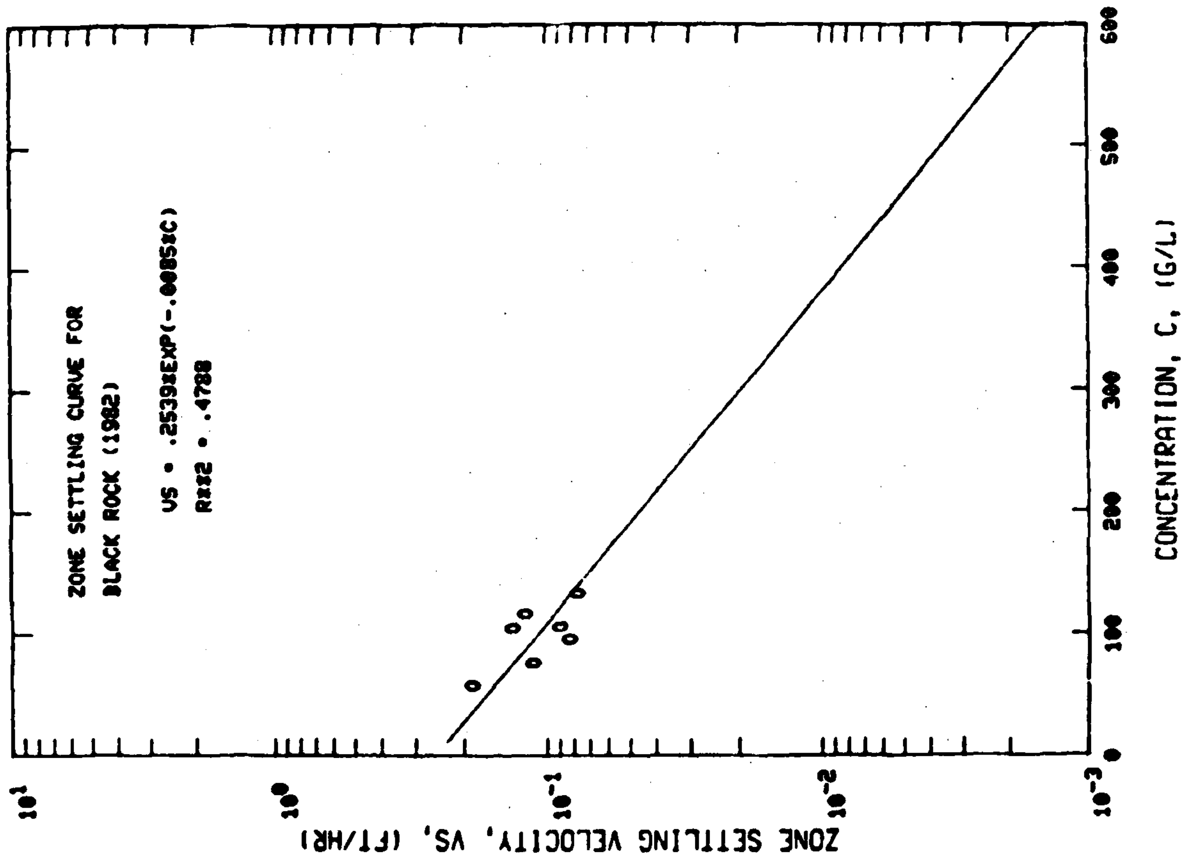
ASHTABULA (124.4 G/L - 1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4

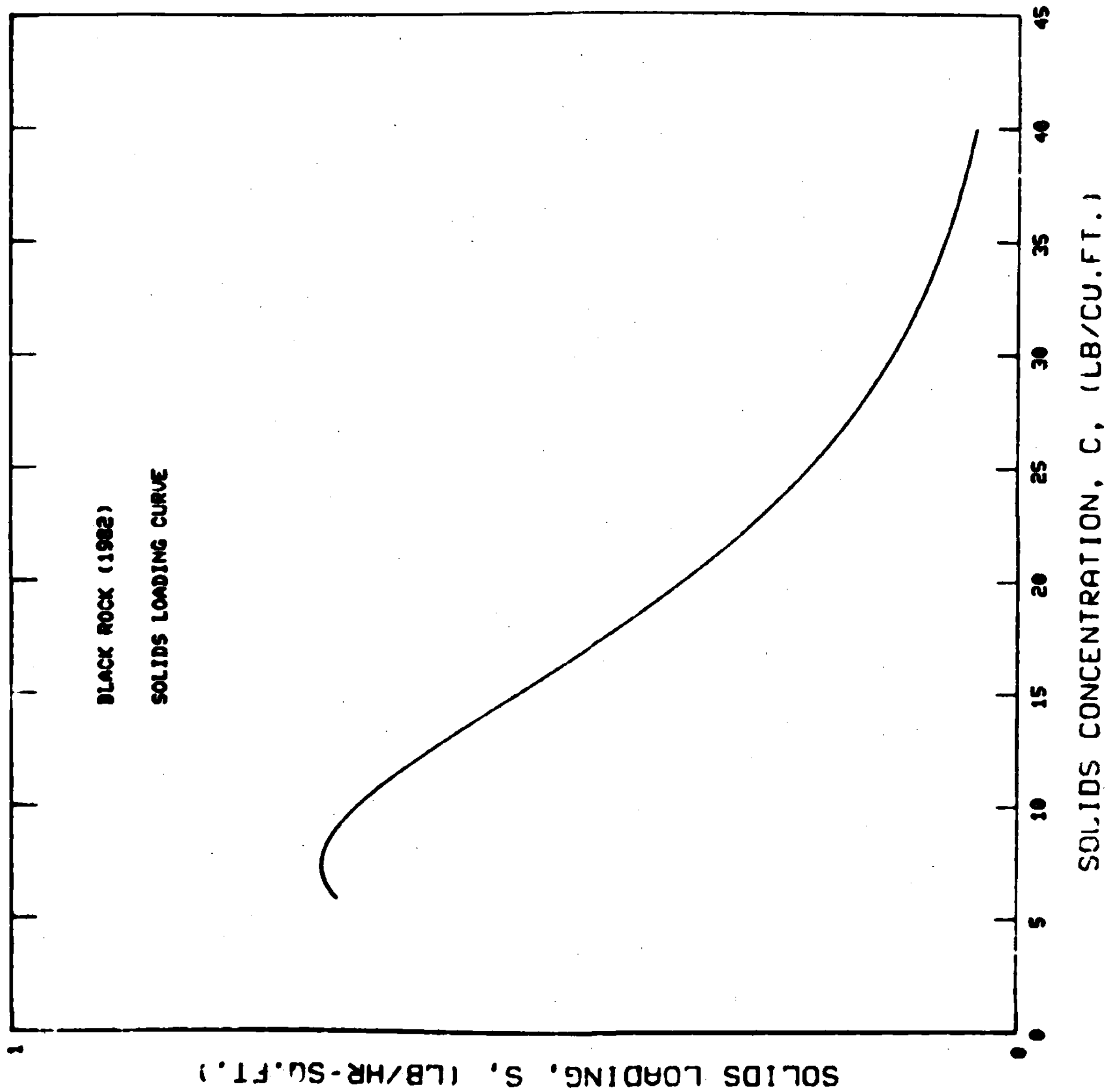


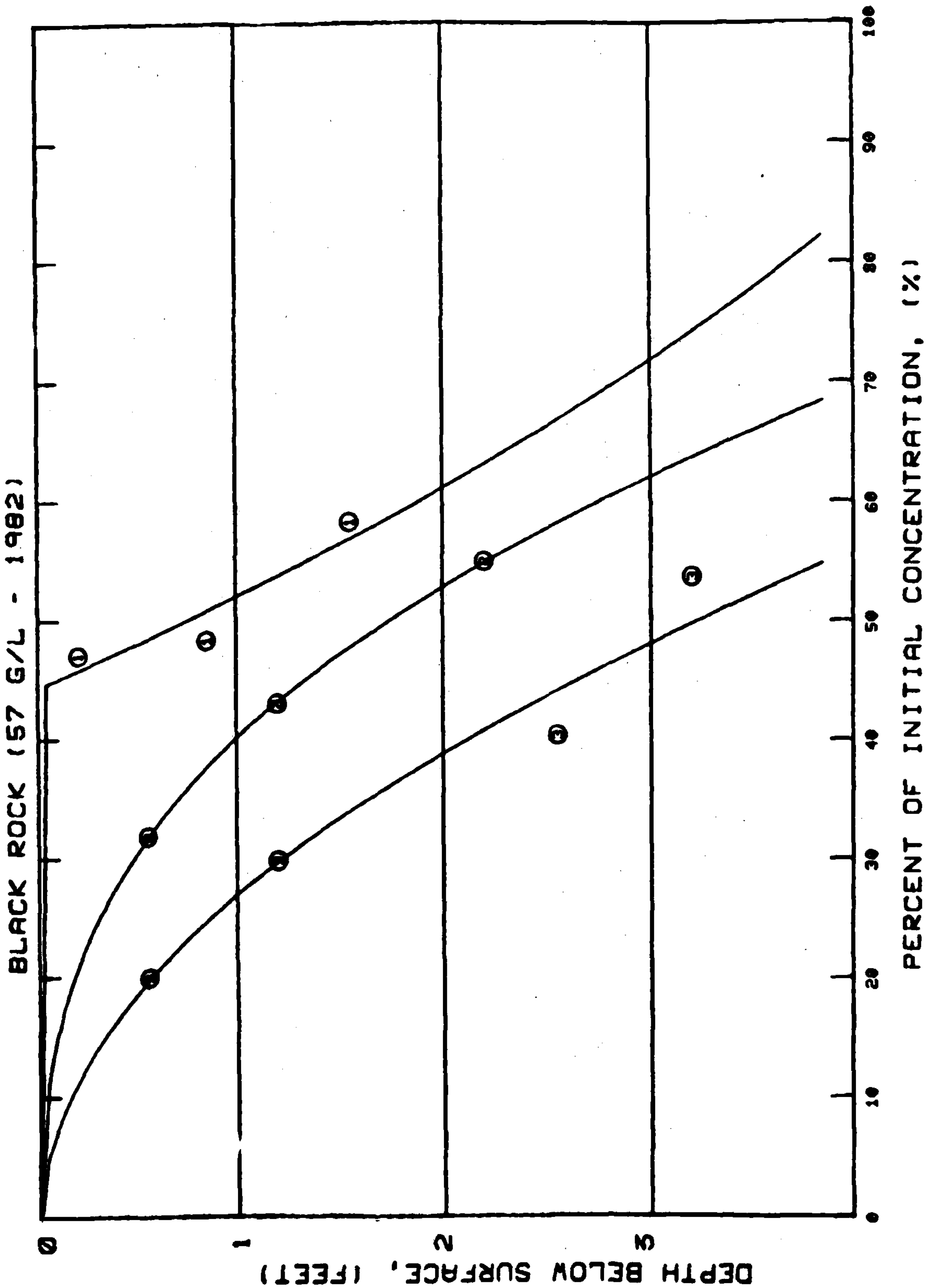
ASHTABULA (124.4 G/L - 1984)
INITIAL SUPERNATANT (MG/L) = 1302.
RETENTION TIME, (HRS)
TSS, (MG/L)
0
20
40
60
80
100
0
100
200
300
400
500

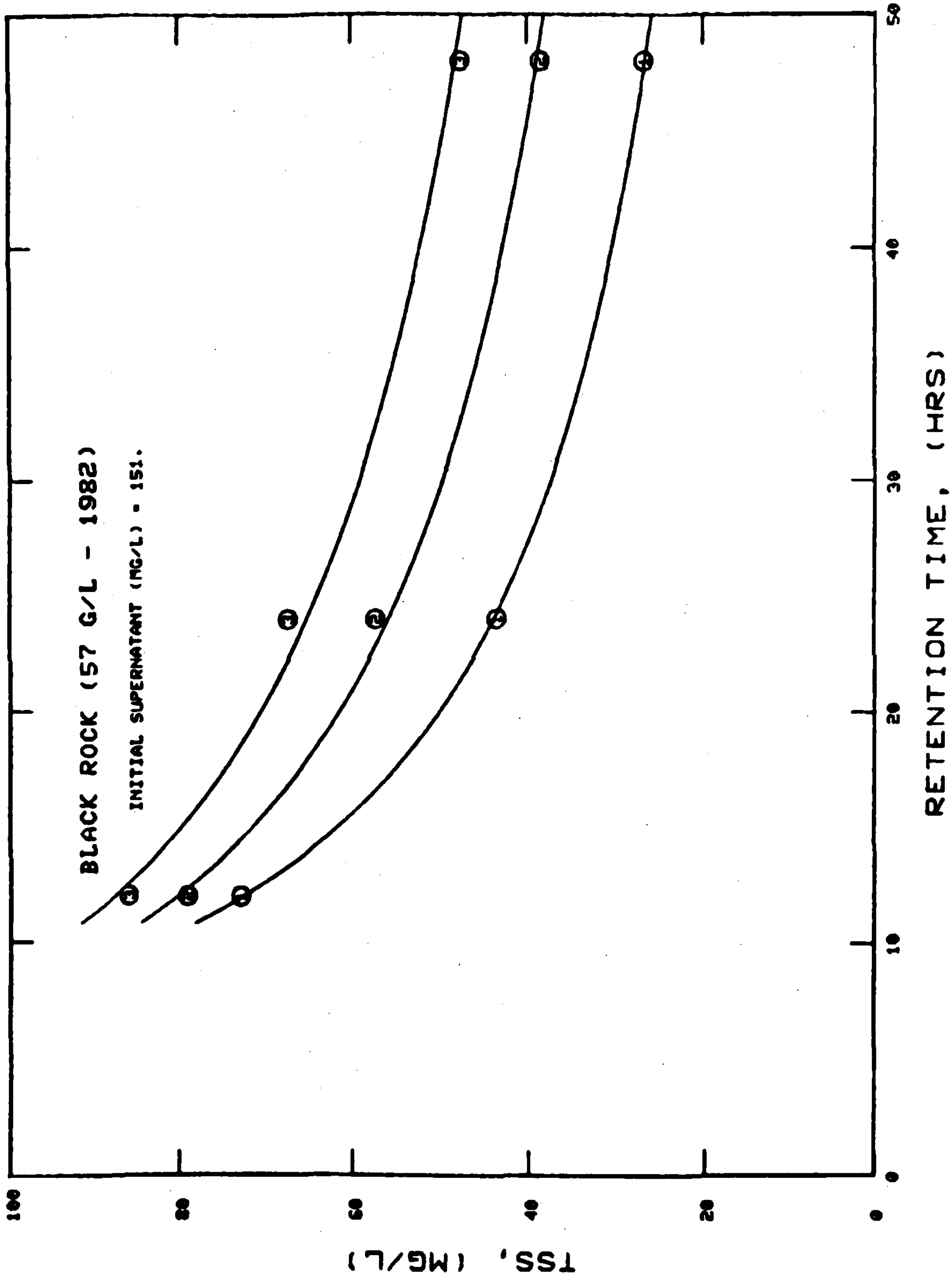


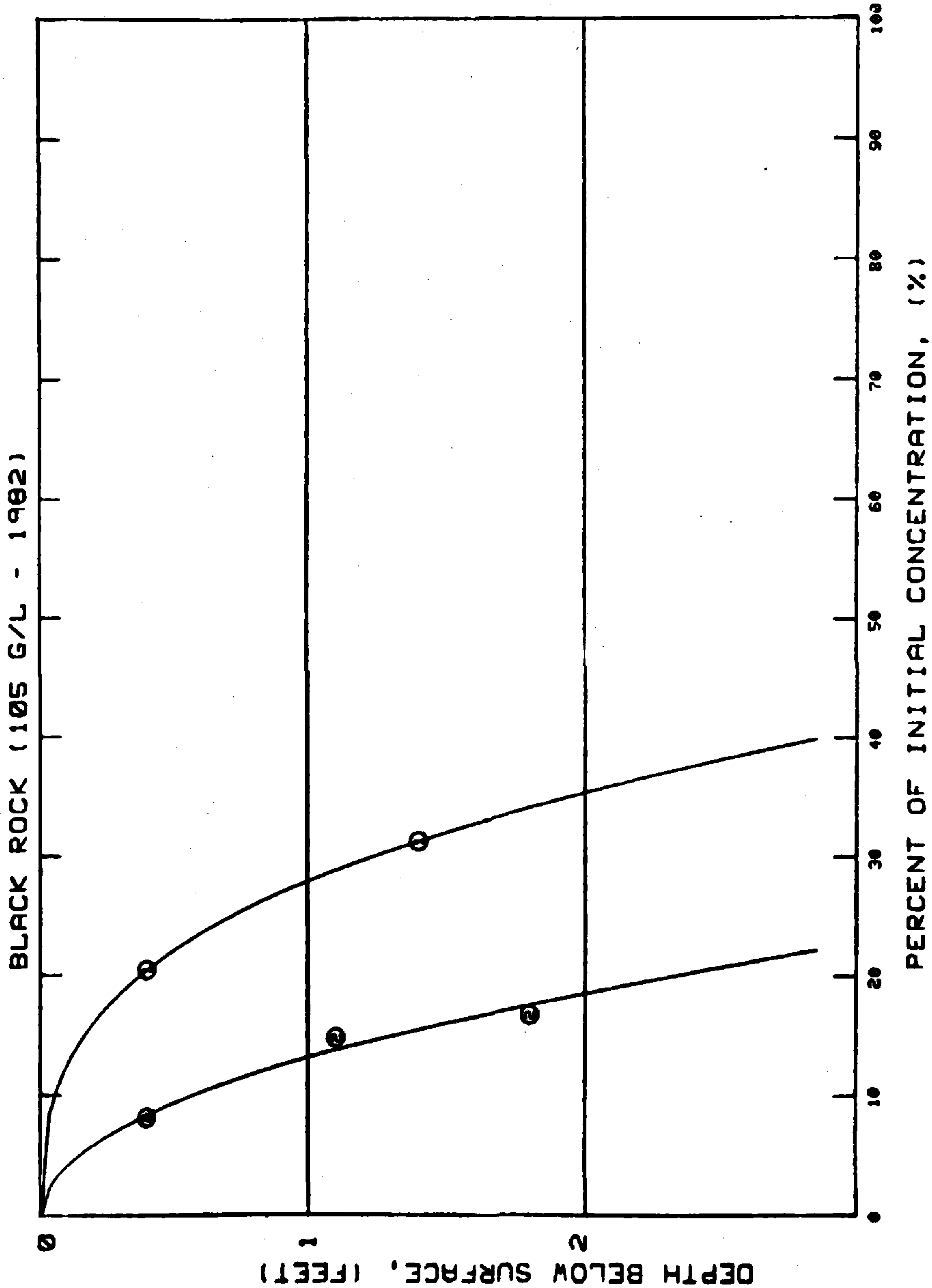
BLACK ROCK (1982)
COMPRESSION SETTLING TEST RESULT
C = 149.1 *(T)**.1629
R**2 = .9976
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2


ZONE SETTLING CURVE FOR
BLACK ROCK (1982)
VS = .2539*EXP(-.0085*C)
R**2 = .4788
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

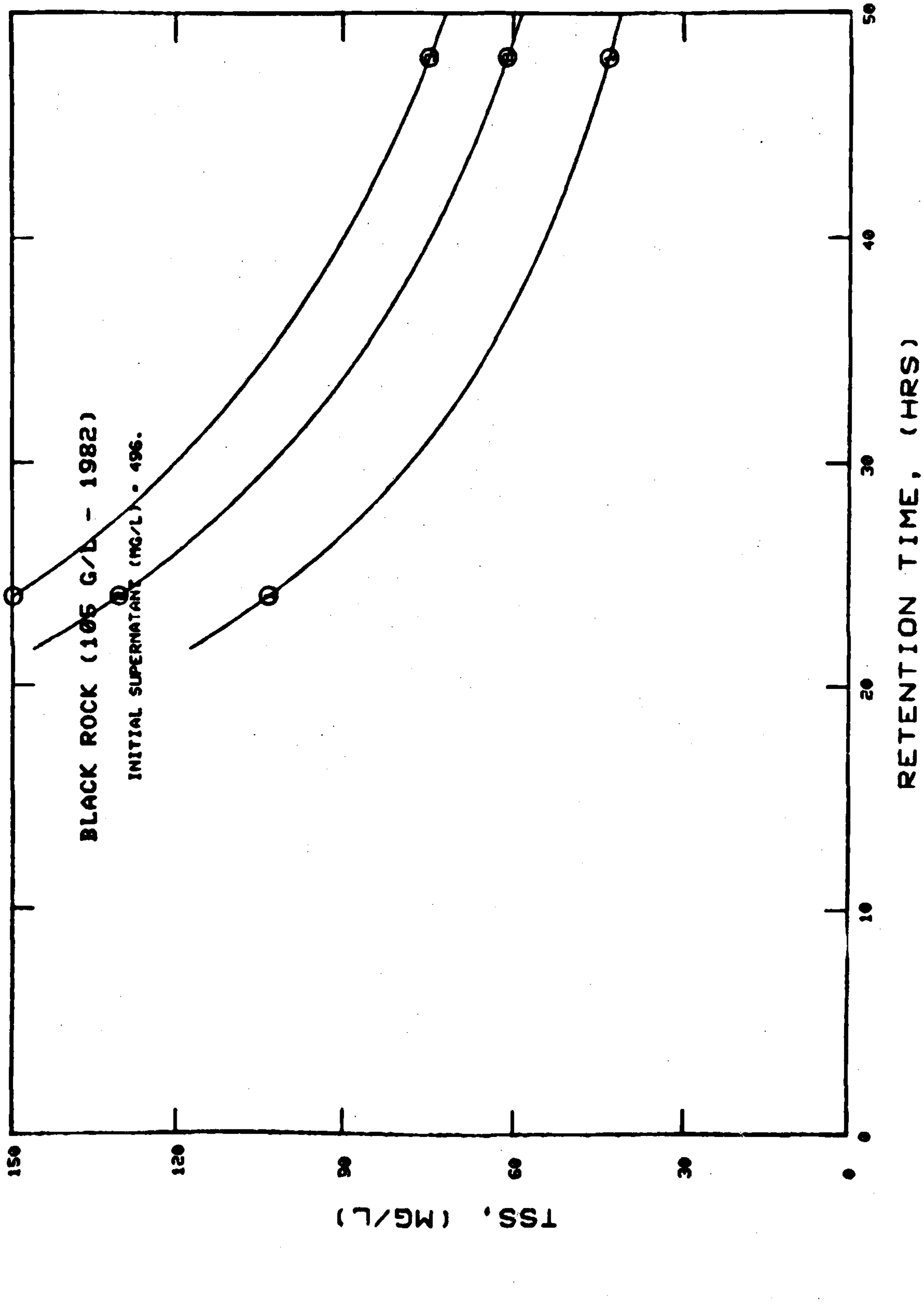

BLACK ROCK (1982)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
35
40
45
0
1

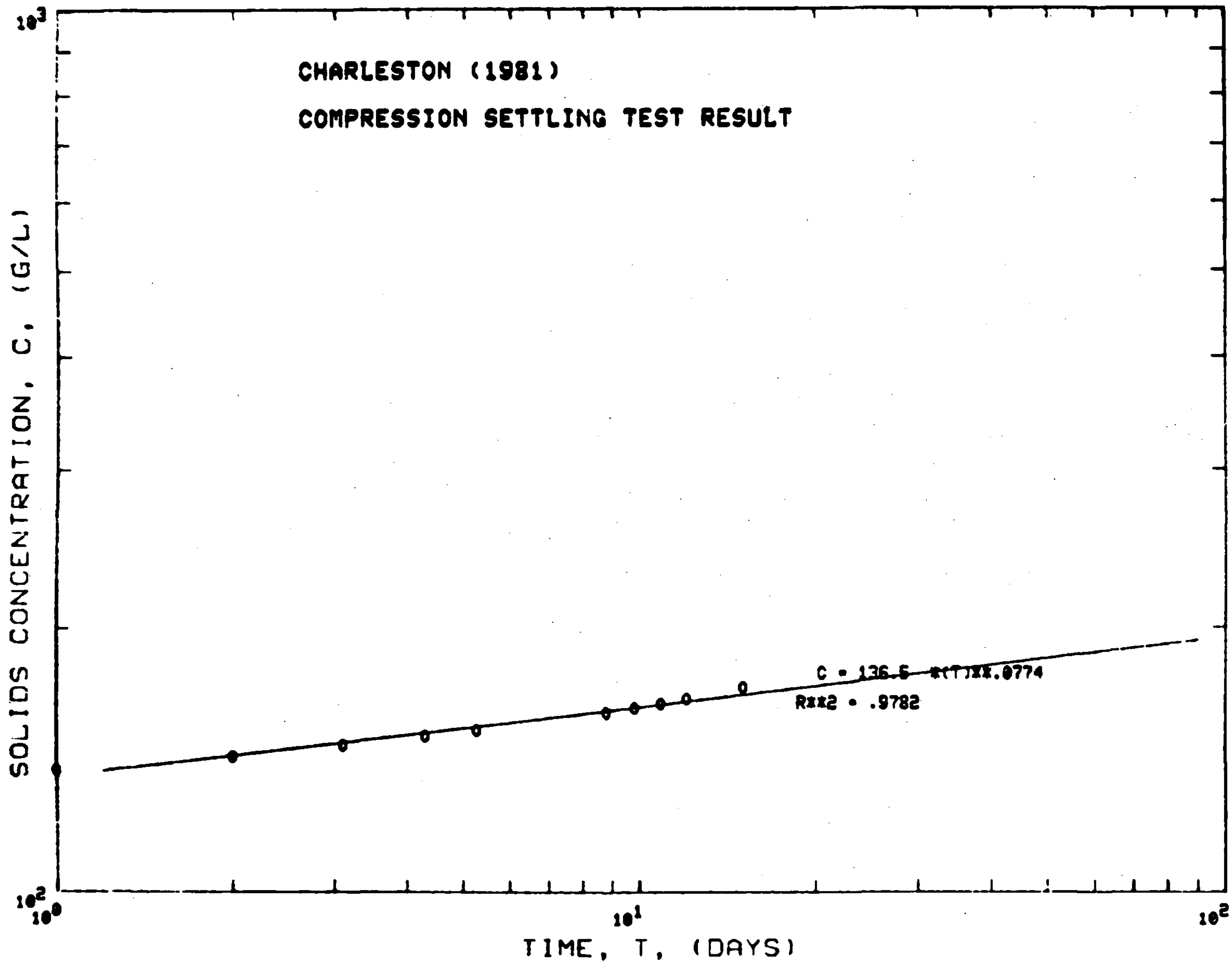

BLACK ROCK (57 G/L - 1982)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3


BLACK ROCK (57 G/L - 1982)
INITIAL SUPERNATANT (MG/L) = 151.
RETENTION TIME, (HRS)
TSS, (MG/L)
0
10
20
30
40
50
0
20
40
60
80
100

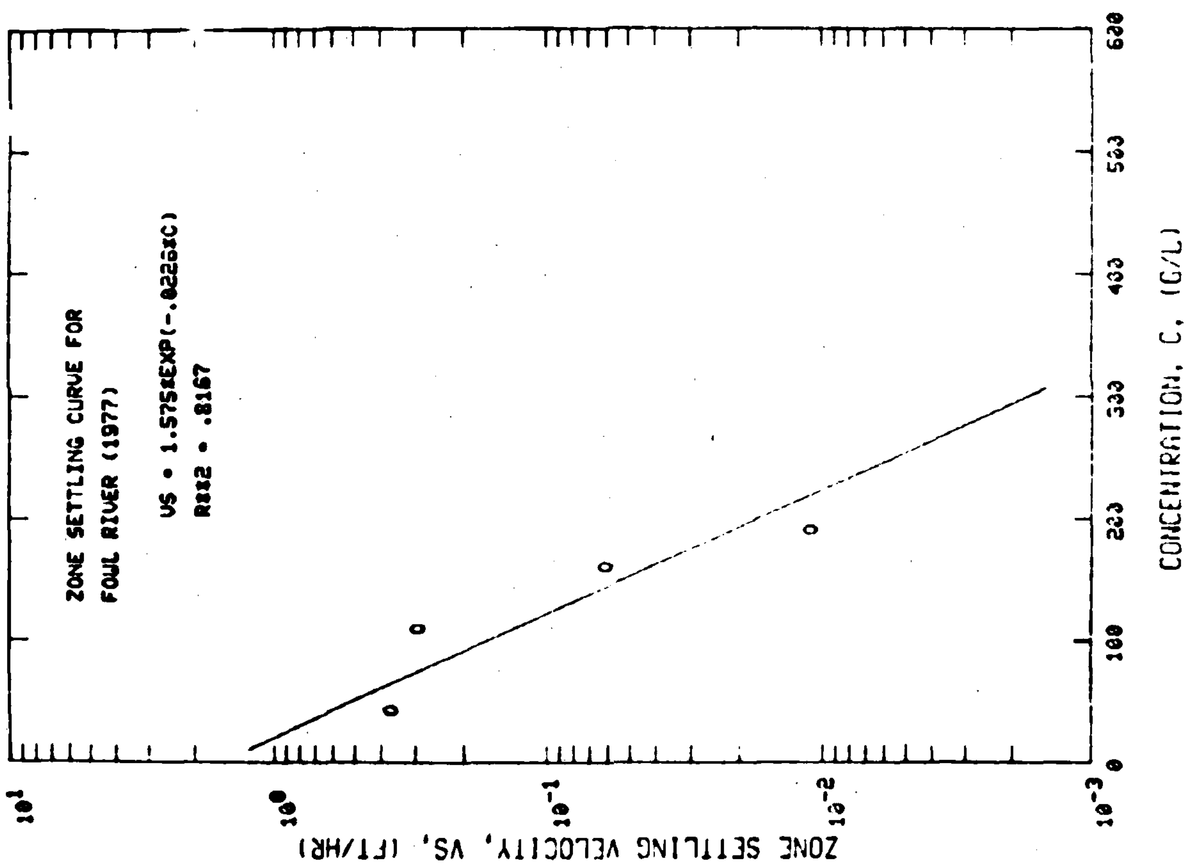


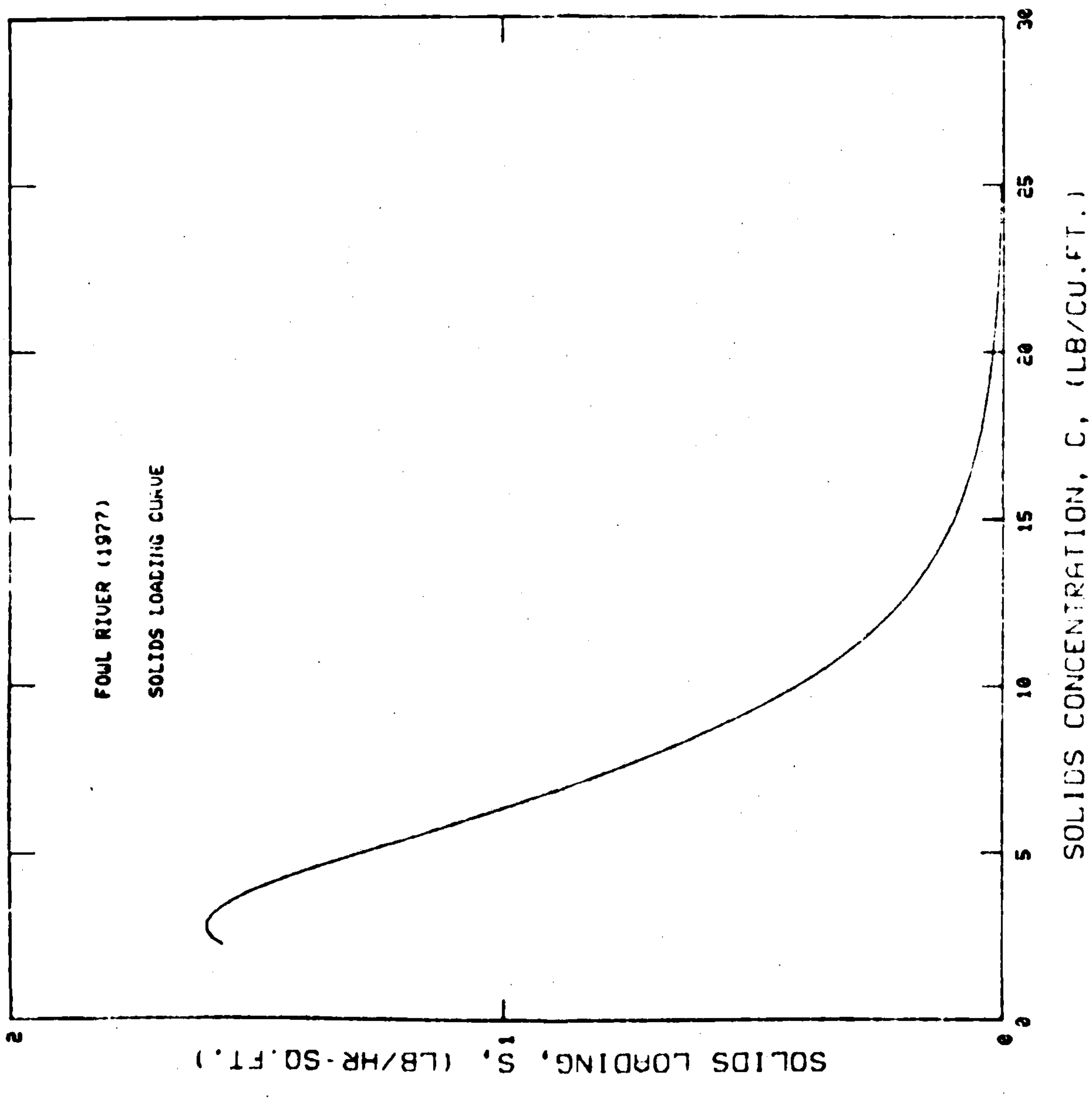
BLACK ROCK (105 G/L - 1982)
PERCENT OF INITIAL CONCENTRATION, (%)
0
10
20
30
40
50
60
70
80
90
100
DEPTH BELOW SURFACE, (FEET)
0
1
2

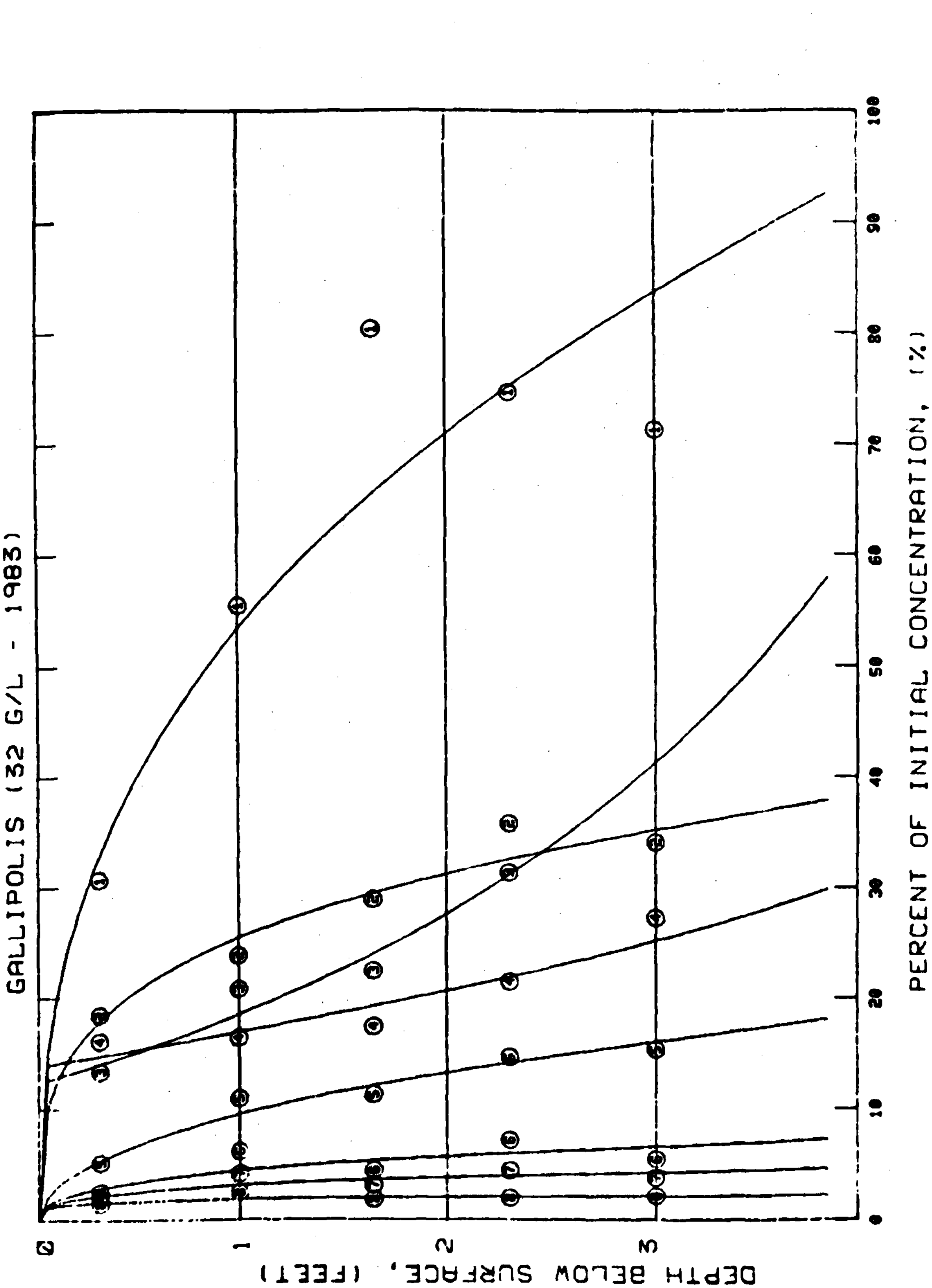

BLACK ROCK (106 G/L - 1982)
INITIAL SUPERNATANT (MG/L) = 496.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
30
60
90
120
150
0
10
20
30
40
50

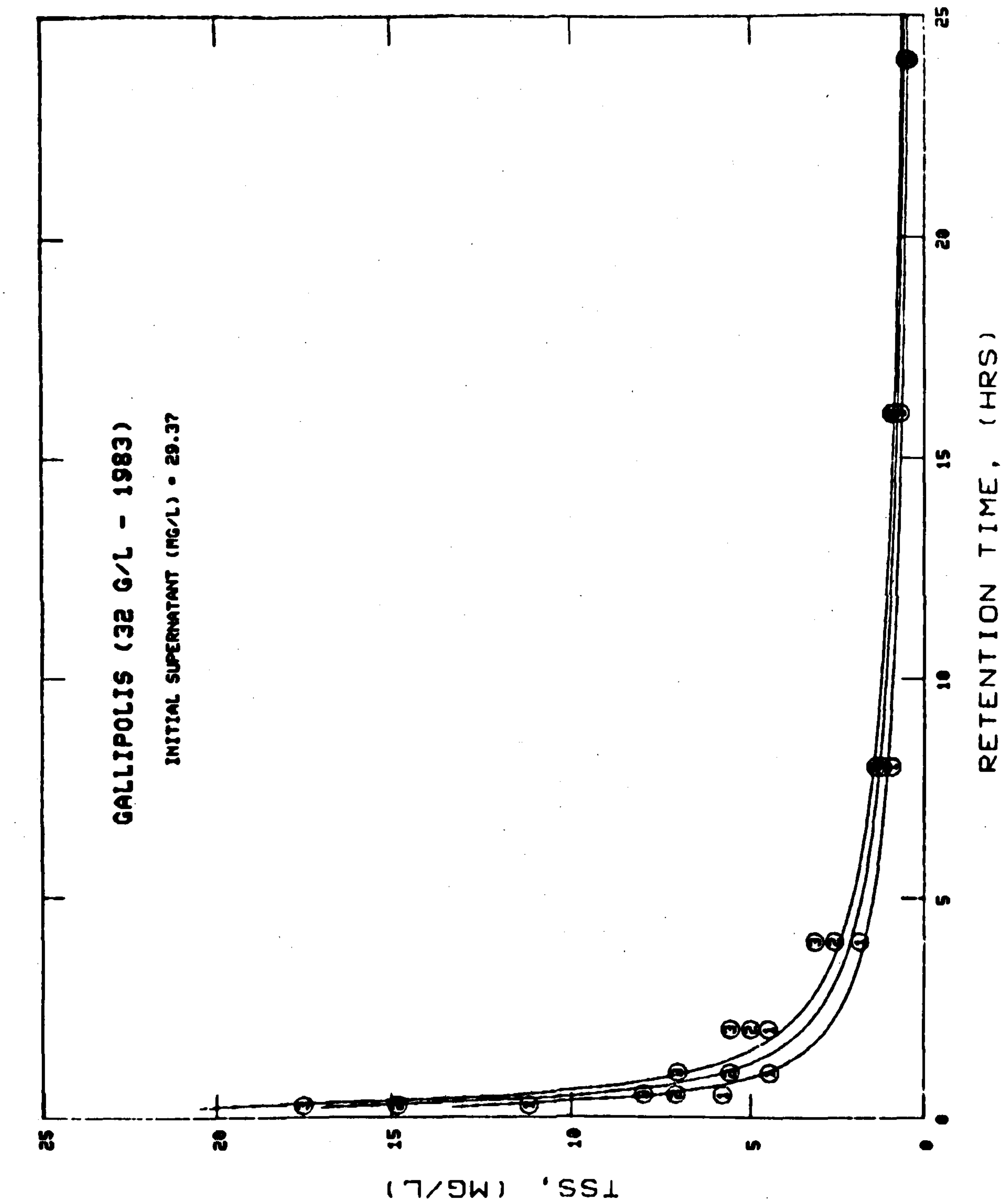


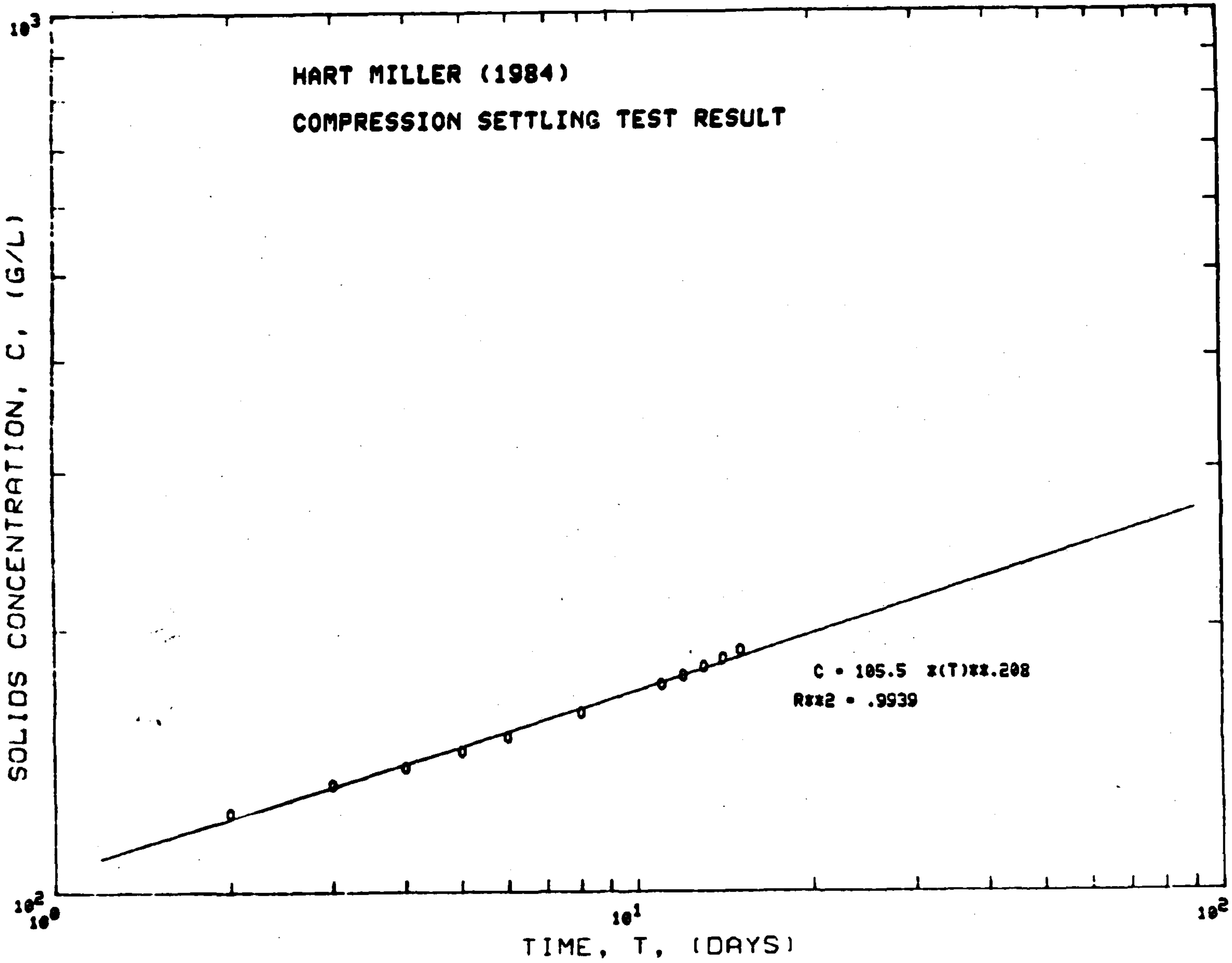
CHARLESTON (1981)
COMPRESSION SETTLING TEST RESULT
C = 136.5 *(T)**.0774
R**2 = .9782
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2


ZONE SETTLING CURVE FOR
FOWL RIVER (1977)
VS = 1.575*EXP(-.0225*C)
R**2 = .8167
CONCENTRATION, C, (G/L)
ZONE SETTLING VELOCITY, VS, (FT/HR)
0
100
200
300
400
500
600
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}

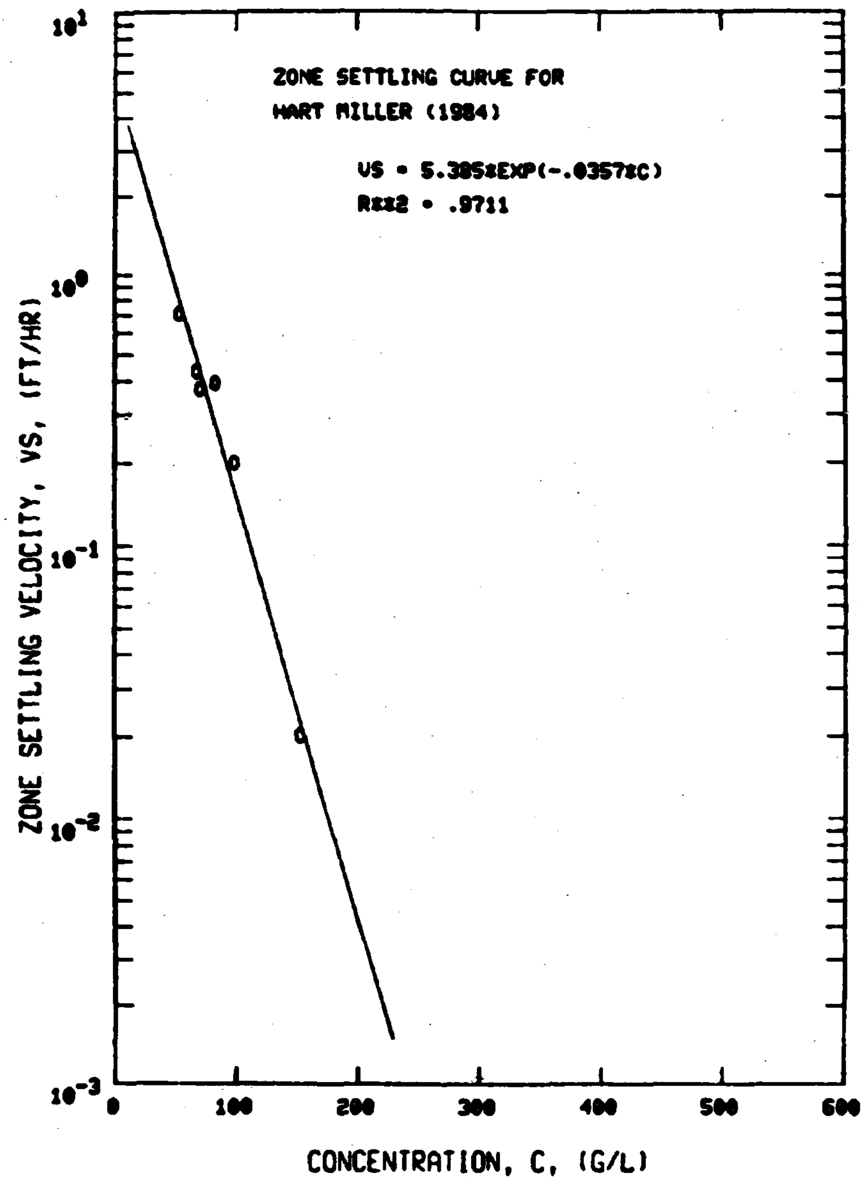

FOWL RIVER (1977)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
1
2

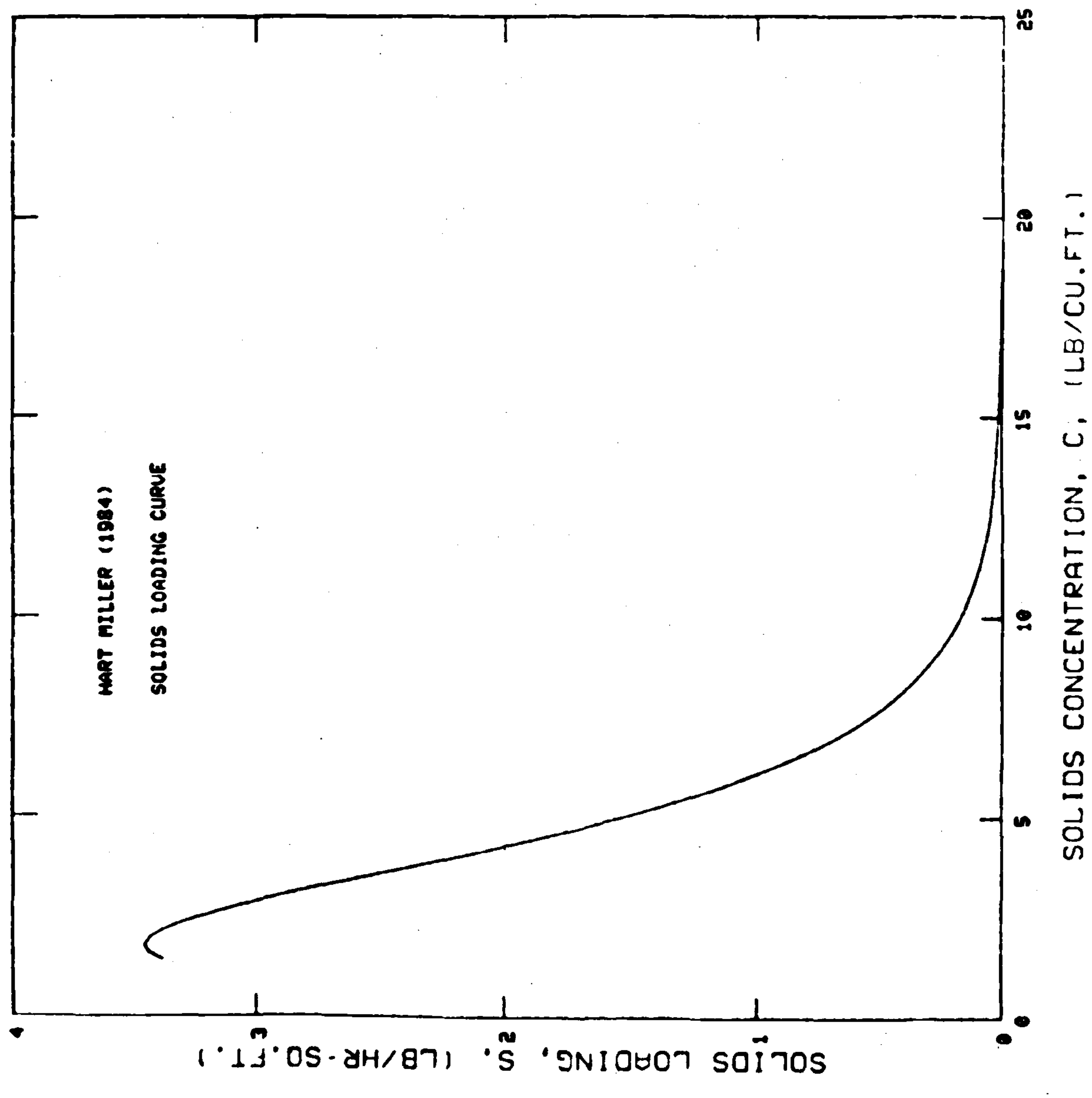

GALLIPOLIS (32 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3

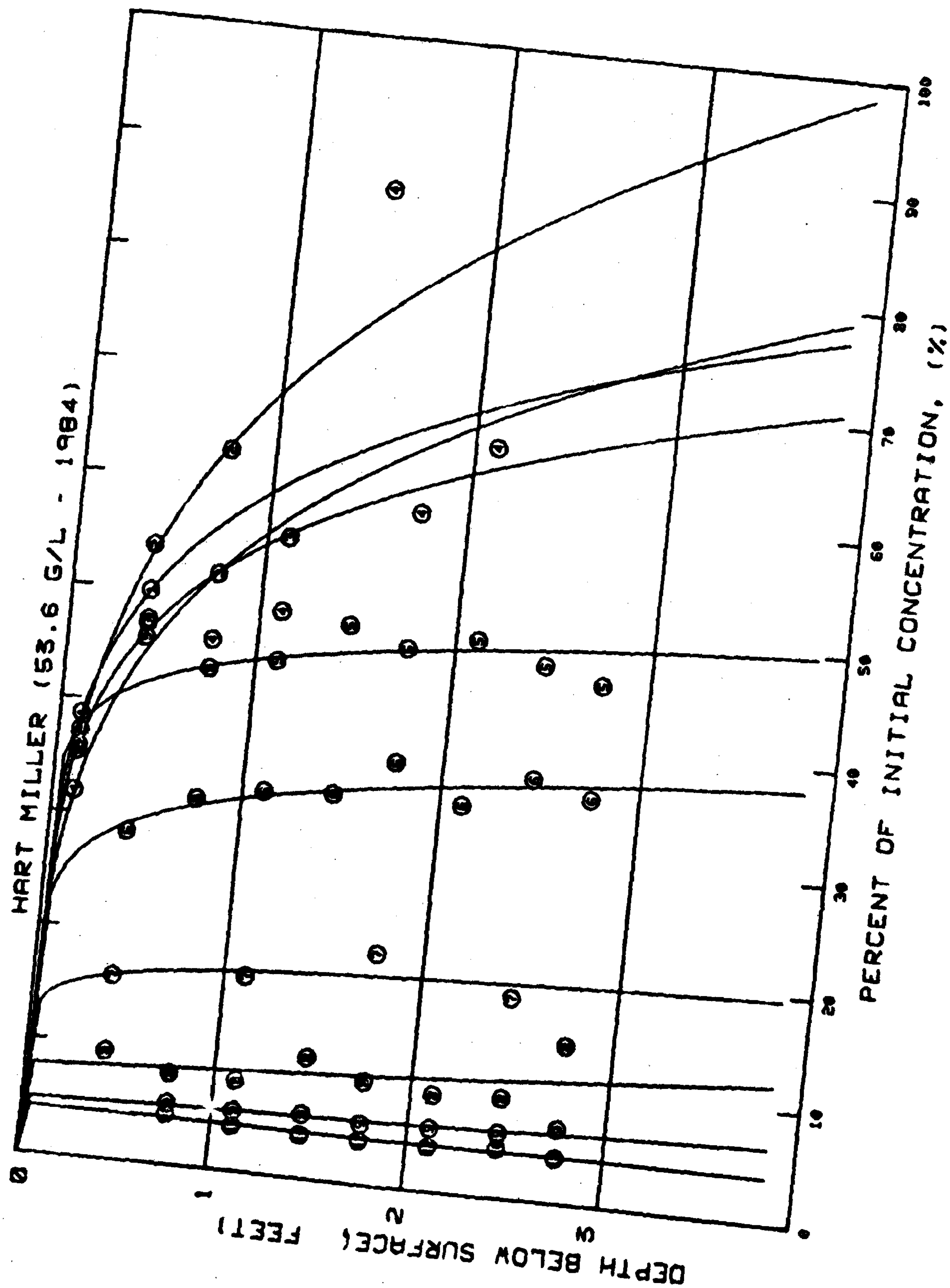

GALLIPOLIS (32 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 29.37
RETENTION TIME, (HRS)
TSS, (MG/L)
0
5
10
15
20
25

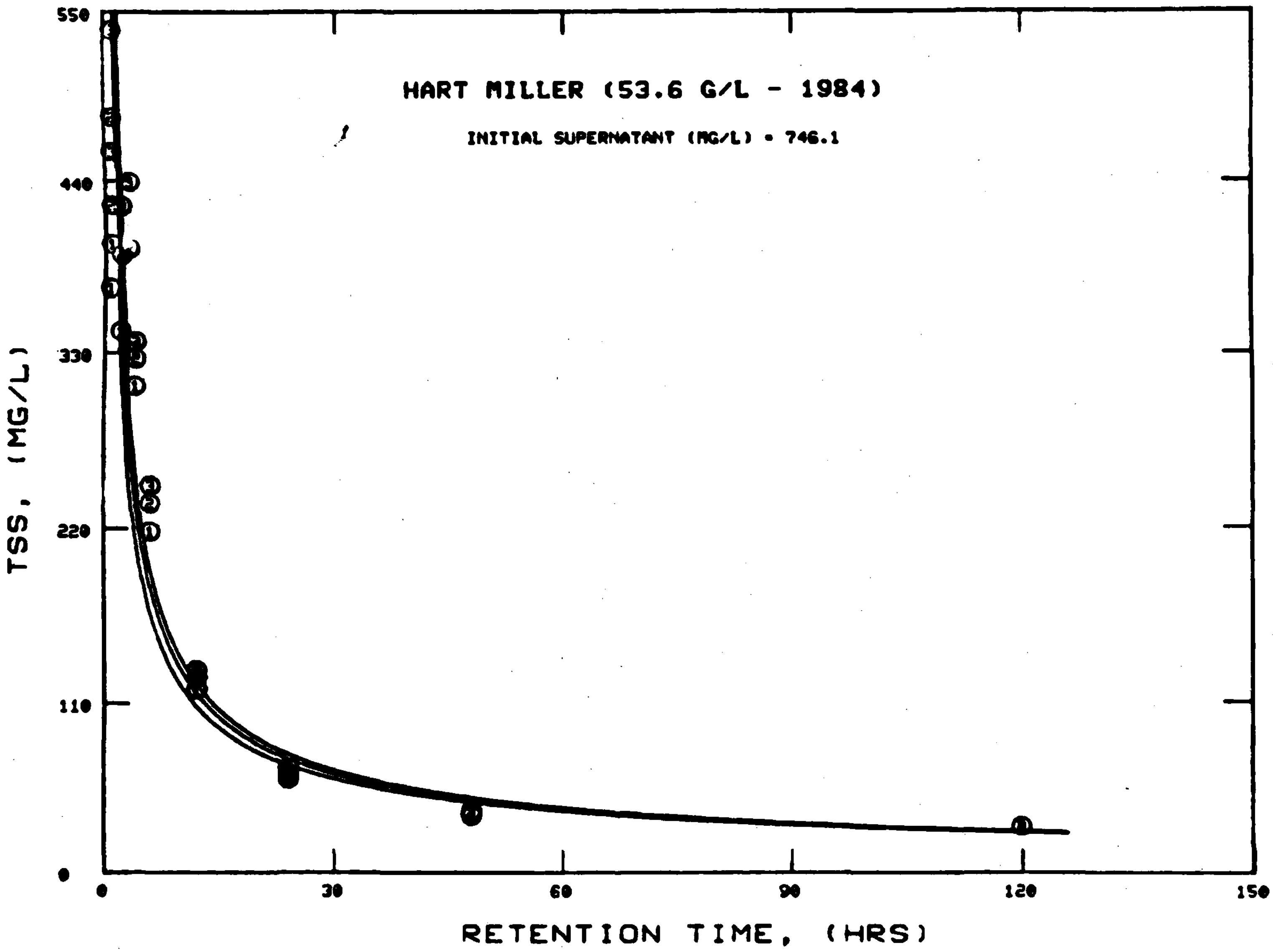


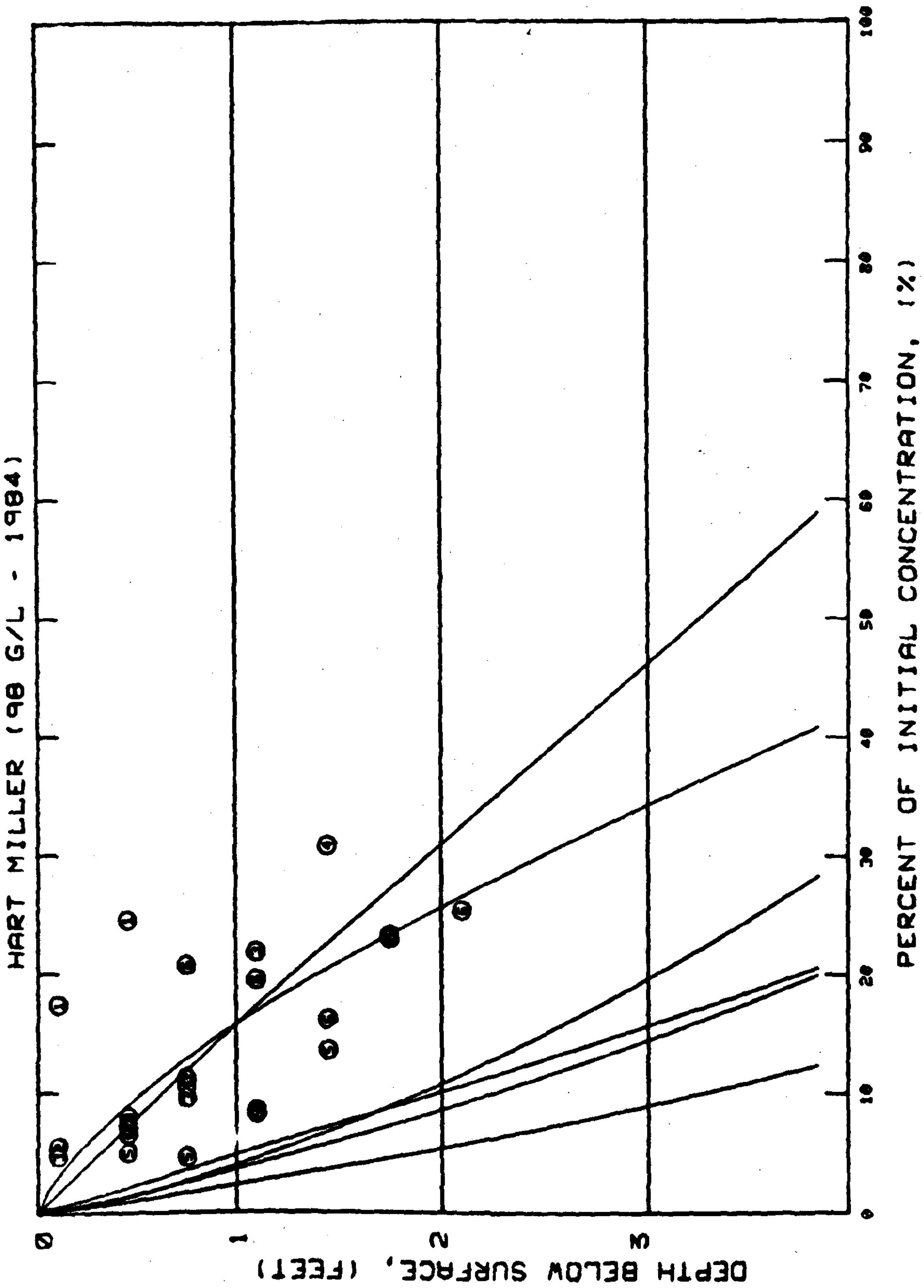
HART MILLER (1984)
COMPRESSION SETTLING TEST RESULT
C = 105.5 *(T)**.208
R**2 = .9939
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)

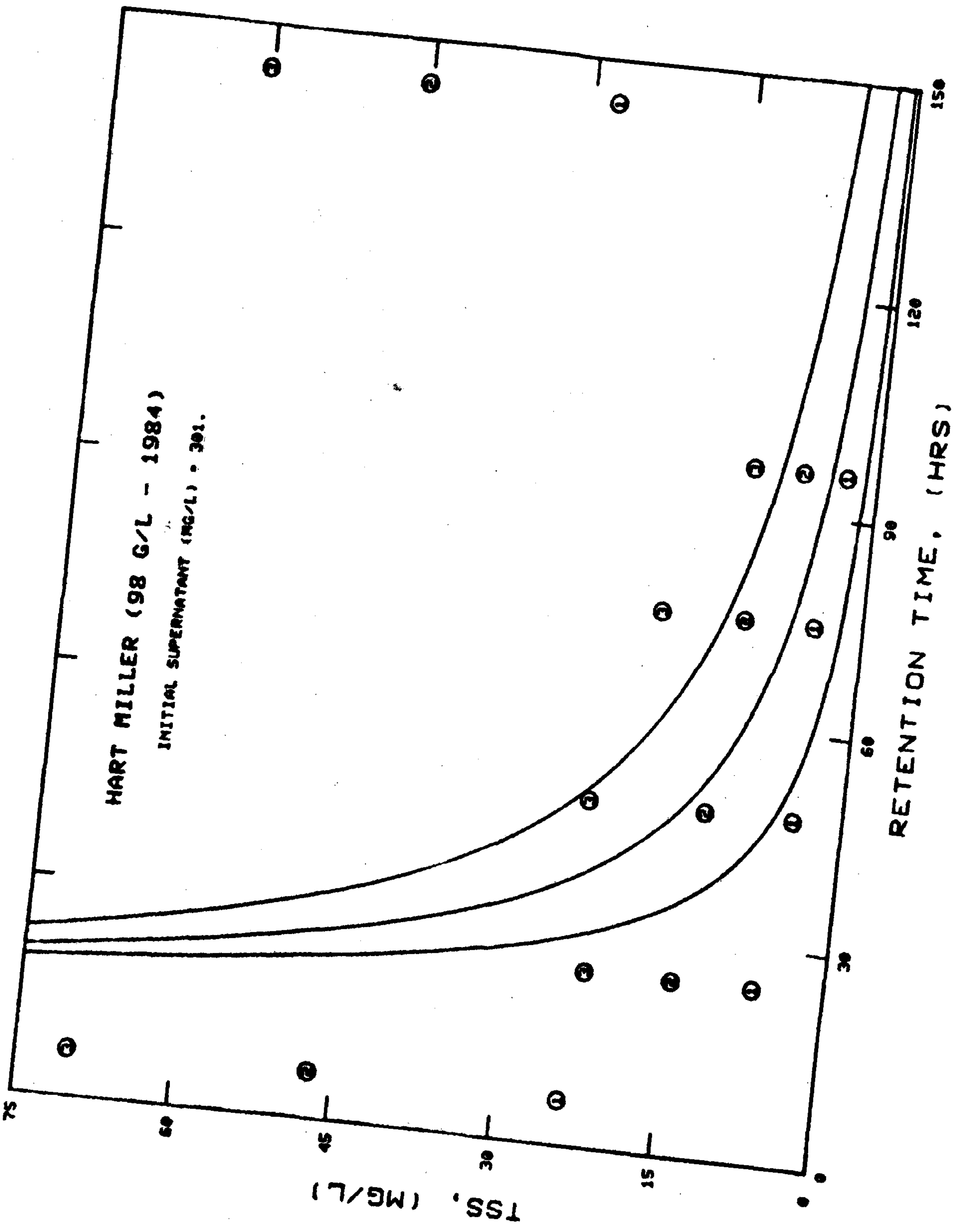

ZONE SETTLING CURVE FOR
HART MILLER (1984)
VS = 5.385*EXP(-.0357*C)
R**2 = .9711
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

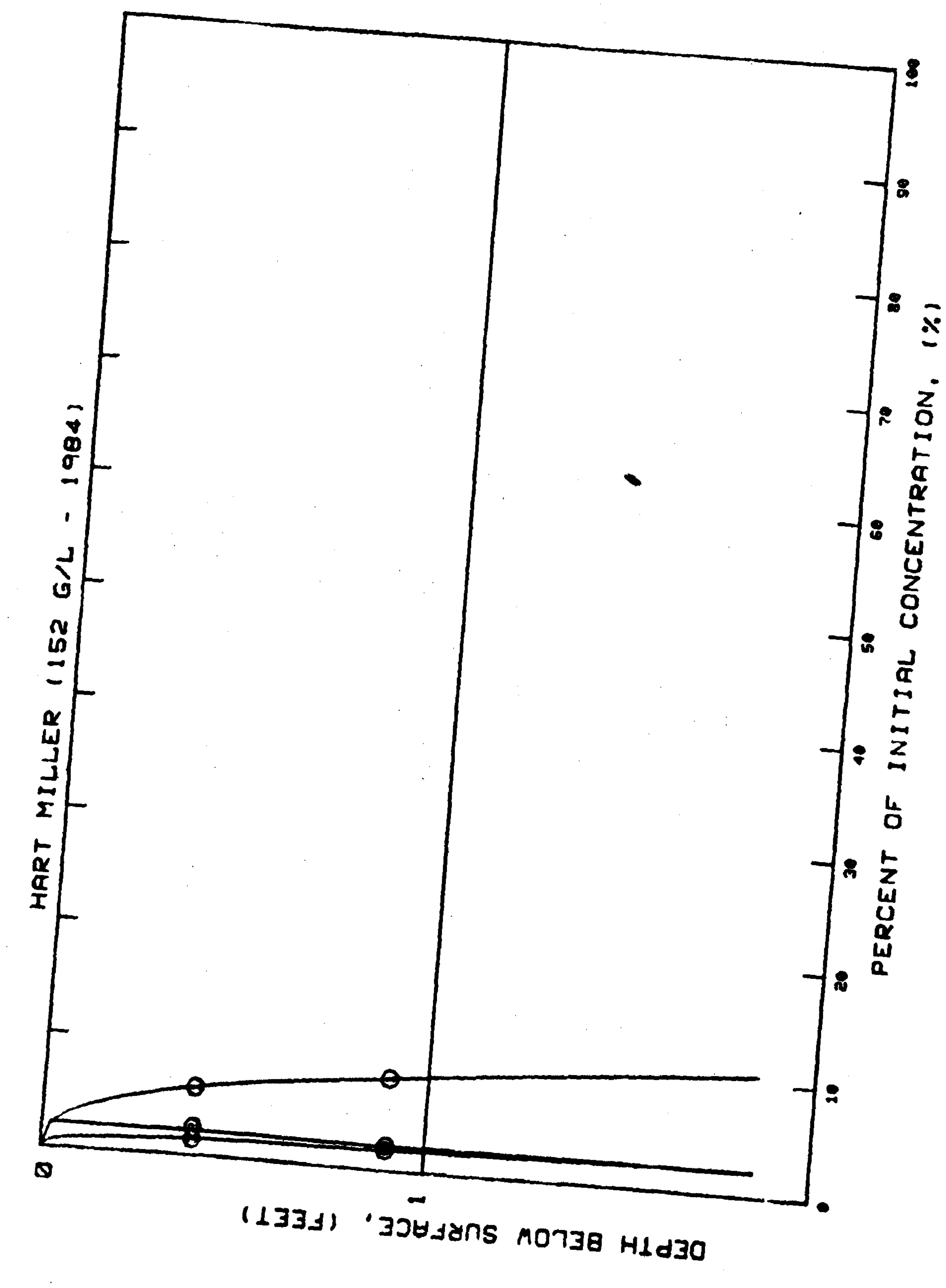

HART MILLER (1984)
SOLIDS LOADING CURVE
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
0
1
2
3
4
5
10
15
20
25

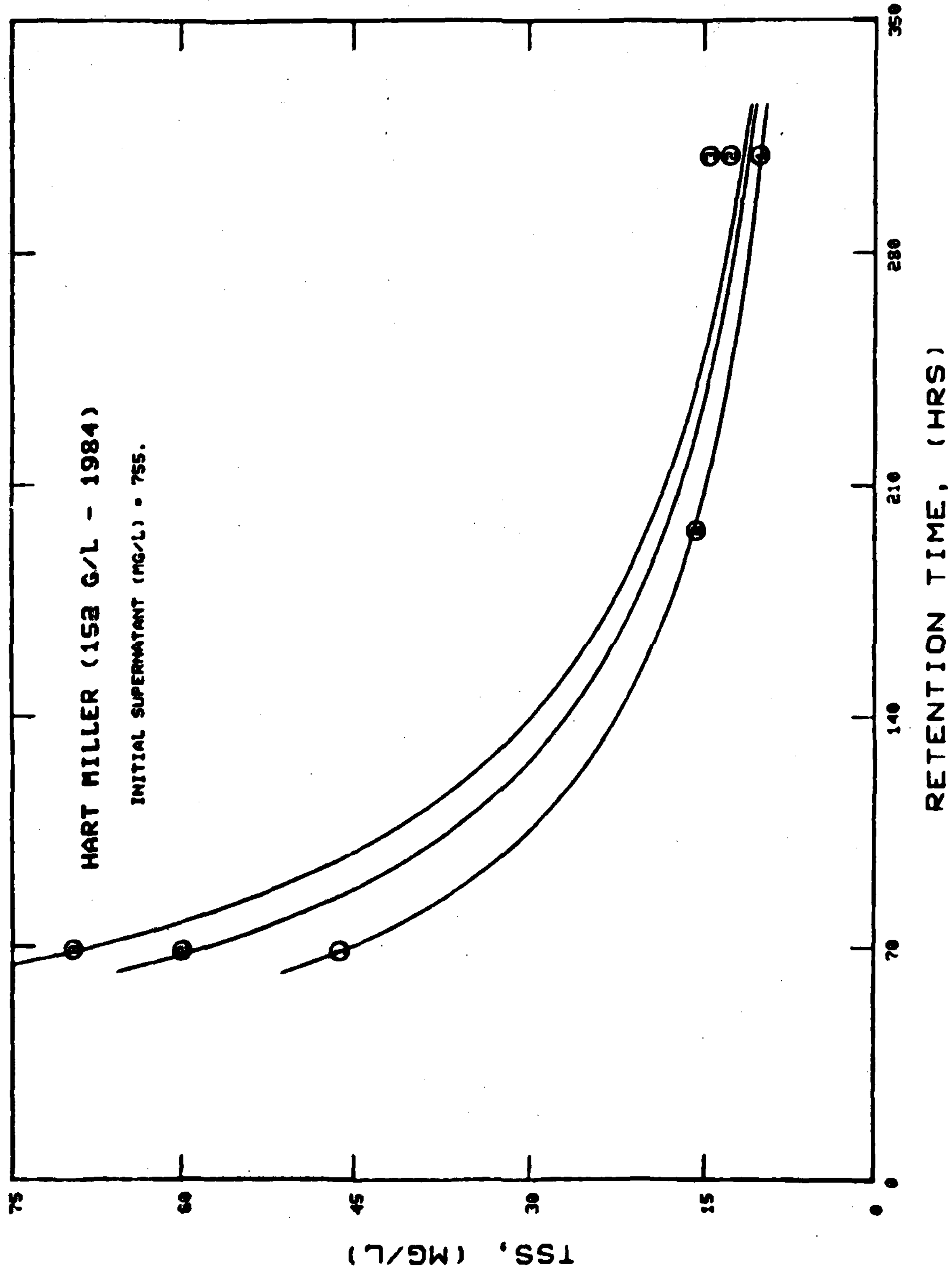

HART MILLER (53.6 G/L - 1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE(FEET)
0
1
2
3
10
20
30
40
50
60
70
80
90
100


HART MILLER (53.6 G/L - 1984)
INITIAL SUPERNATANT (MG/L) = 746.1
TSS, (MG/L)
550
440
330
220
110
0
0
30
60
90
120
150
RETENTION TIME, (HRS)

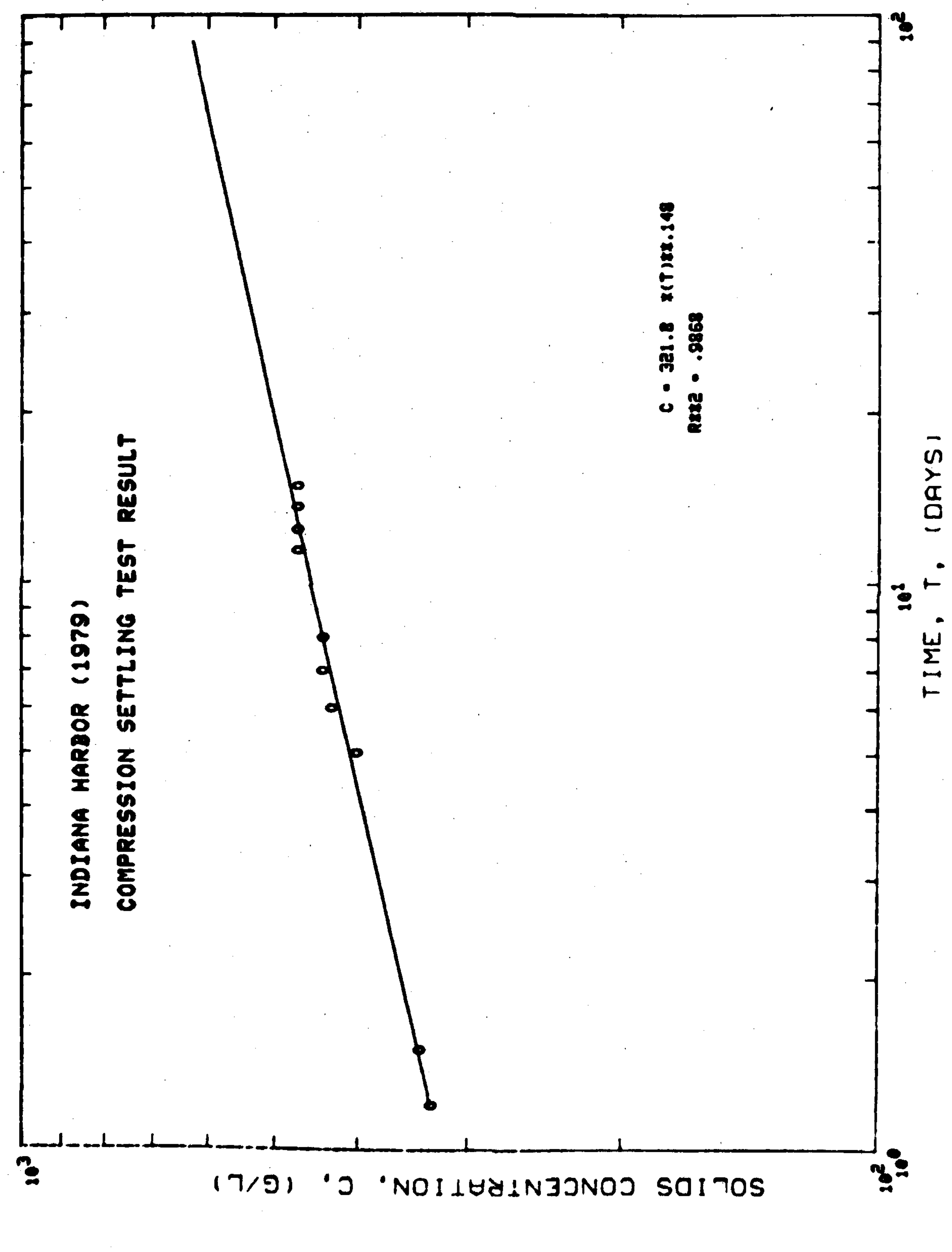

HART MILLER (98 G/L - 1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3

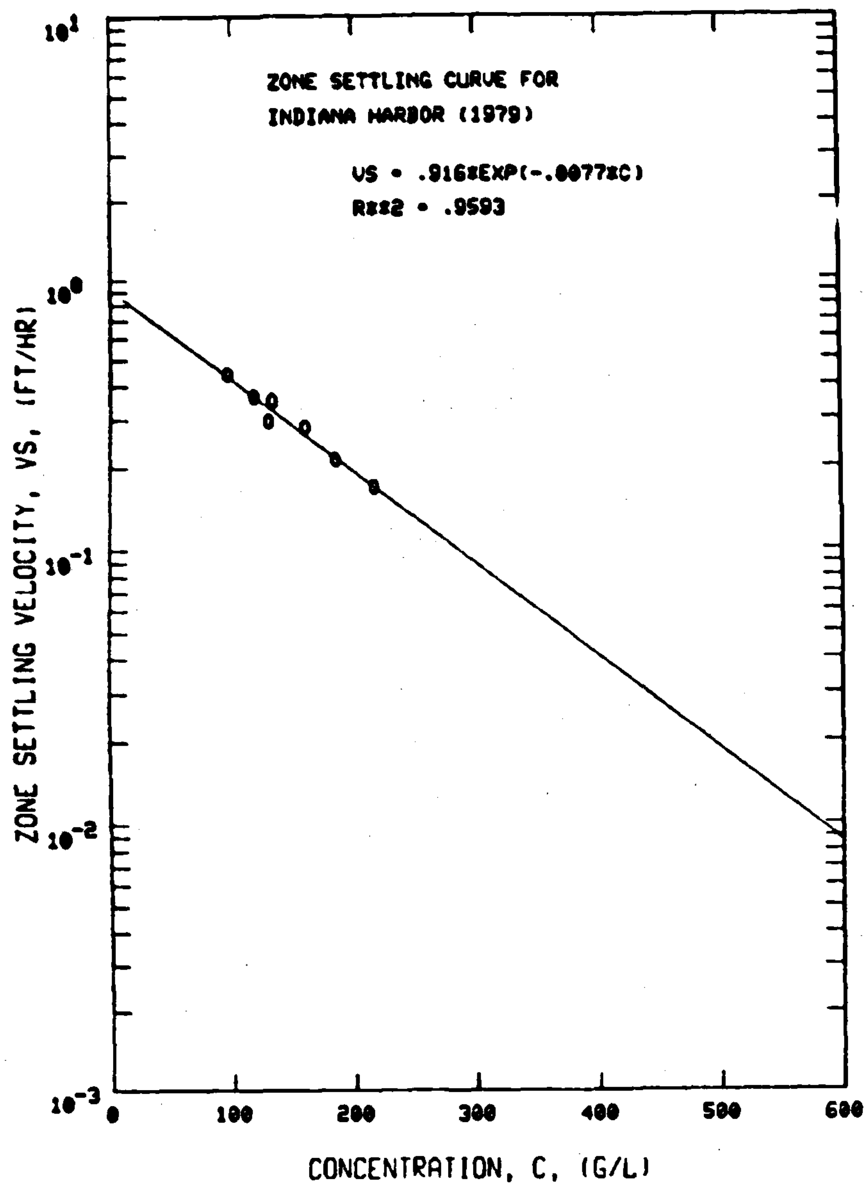

HART MILLER (98 G/L - 1984)
INITIAL SUPERNATANT (MG/L) = 301.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
15
30
45
60
75
30
60
90
120
150

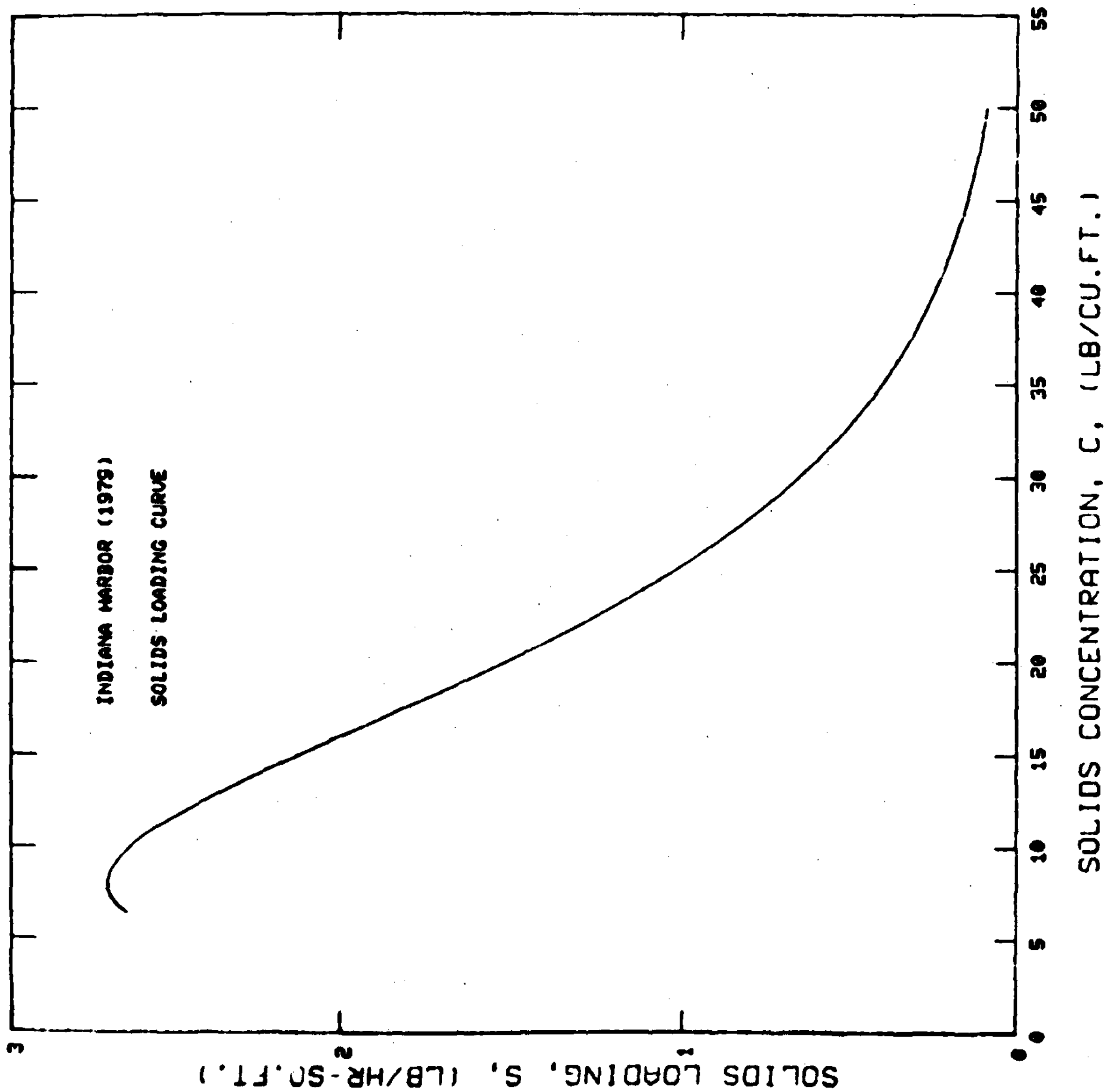

HART MILLER (152 G/L - 1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
1

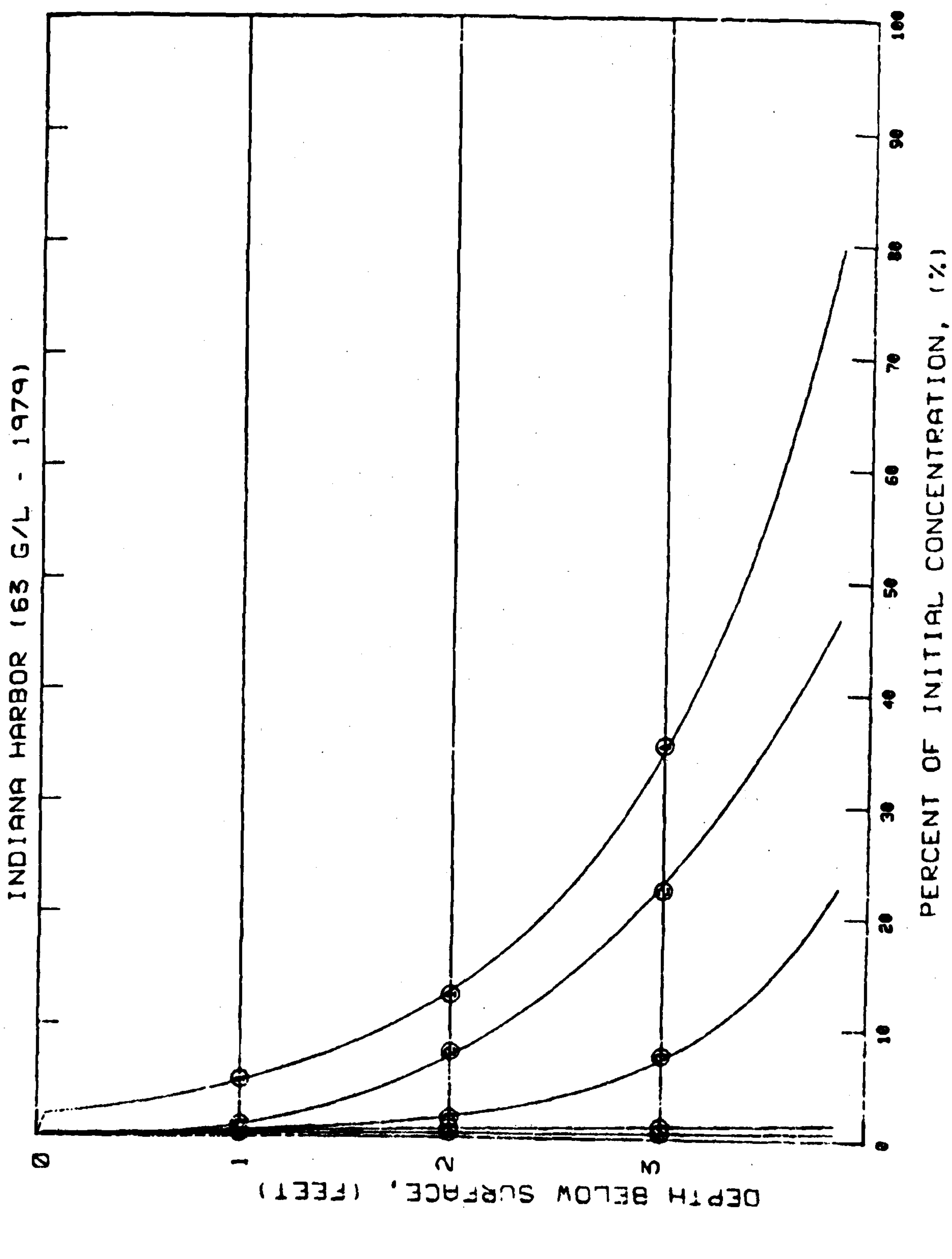


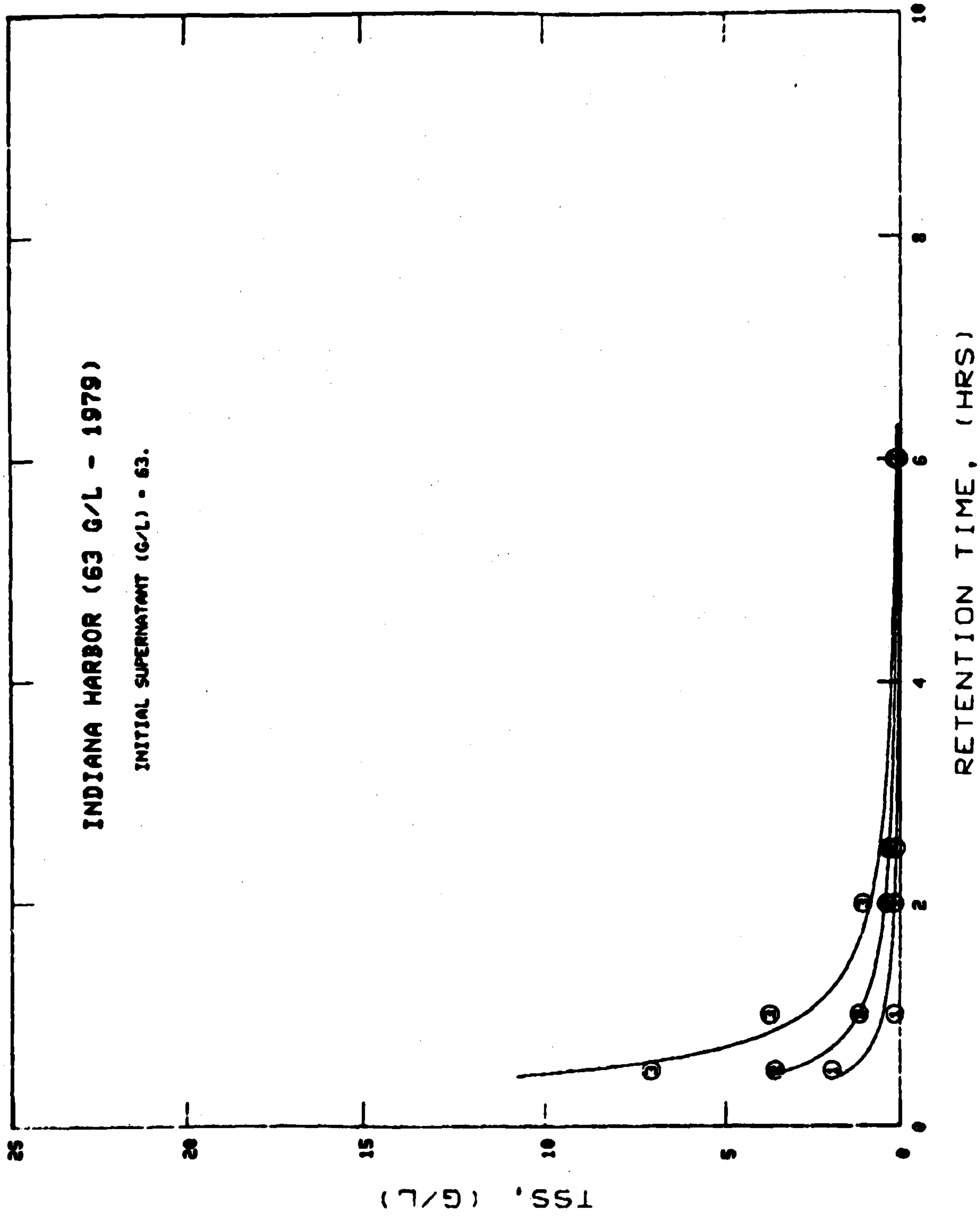
HART MILLER (152 G/L - 1984)
INITIAL SUPERNATANT (MG/L) = 755.
TSS, (MG/L)
75
60
45
30
15
0
RETENTION TIME, (HRS)
0
70
140
210
280
350

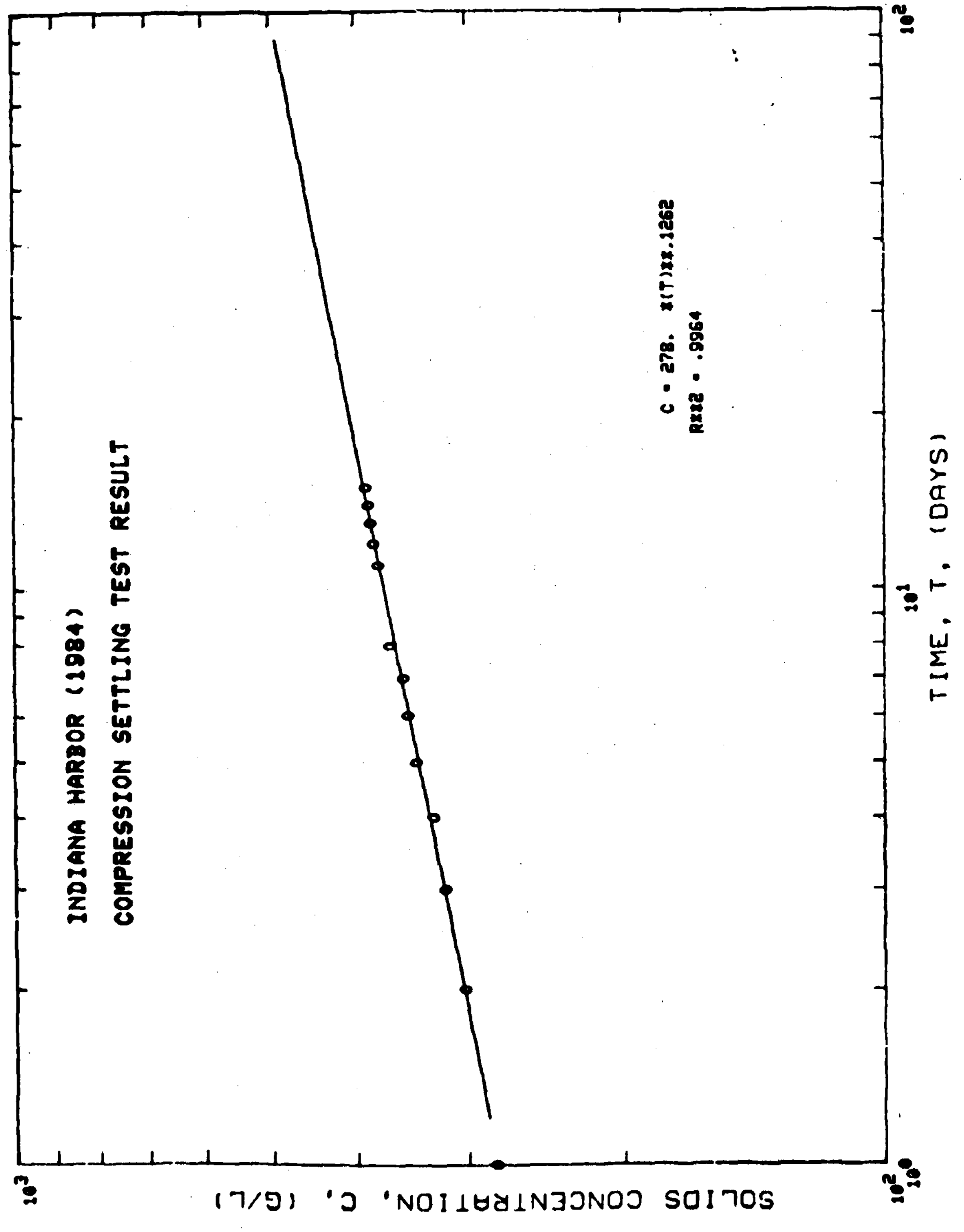

INDIANA HARBOR (1979)
COMPRESSION SETTLING TEST RESULT
C = 321.8 *(T)**.148
R**2 = .9868
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)
10^3
10^2
10^0
10^1
10^2


ZONE SETTLING CURVE FOR
INDIANA HARBOR (1979)
VS = .916*EXP(-.0077*C)
R**2 = .9593
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

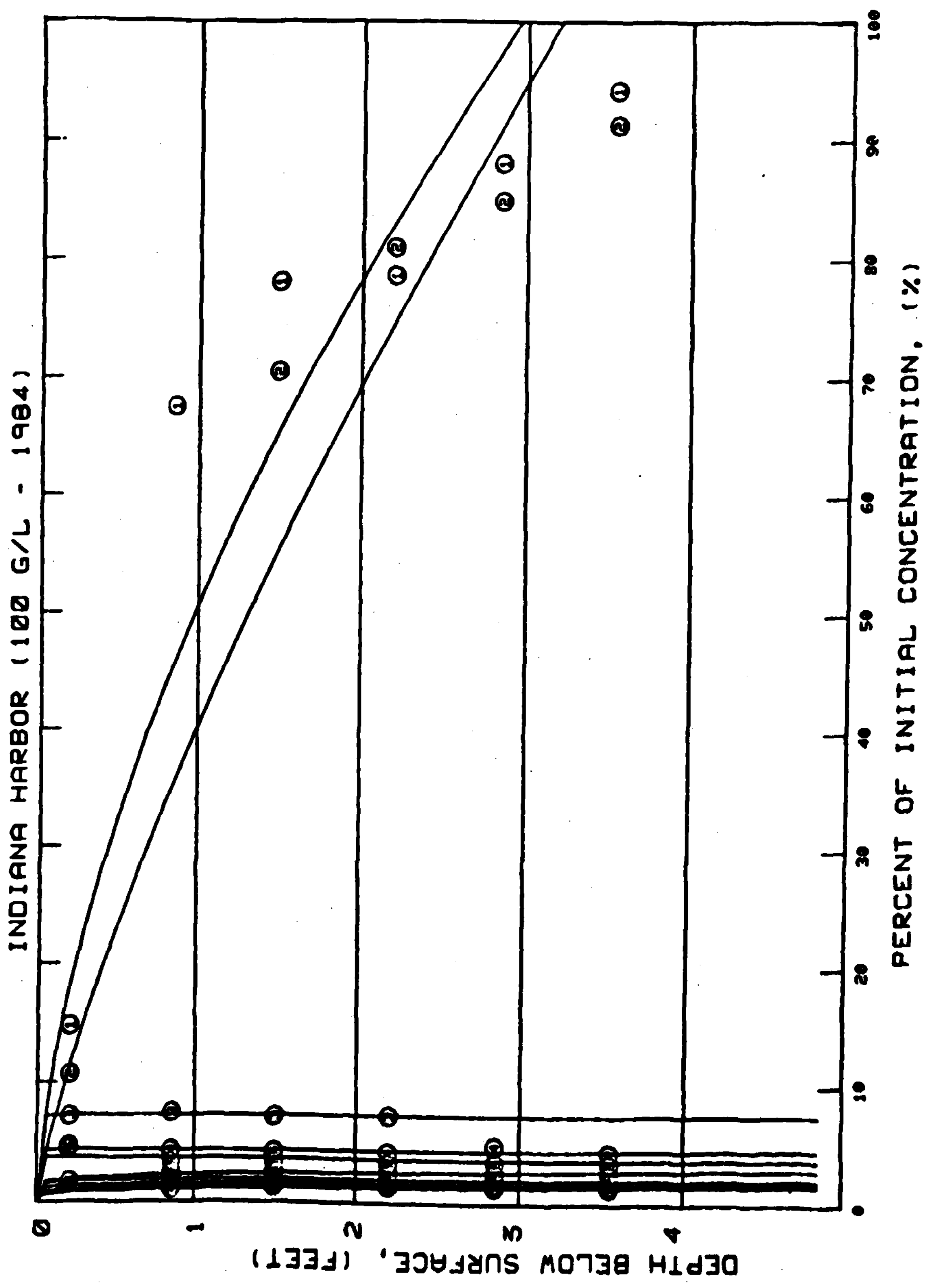

INDIANA HARBOR (1979)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
35
40
45
50
55
0
1
2
3

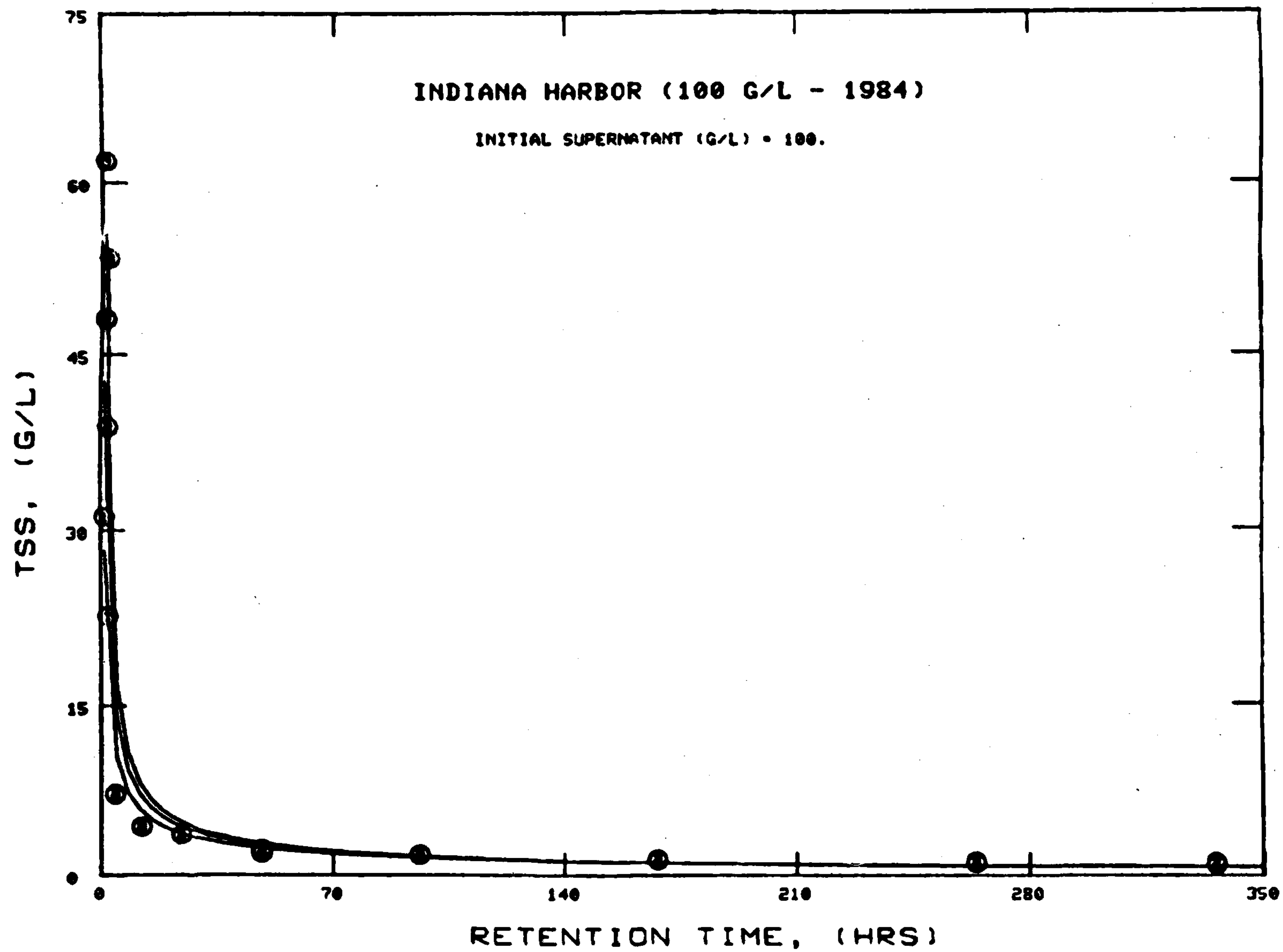

INDIANA HARBOR (63 G/L - 1979)
PERCENT OF INITIAL CONCENTRATION, (%)
0
10
20
30
40
50
60
70
80
90
100
DEPTH BELOW SURFACE, (FEET)
0
1
2
3

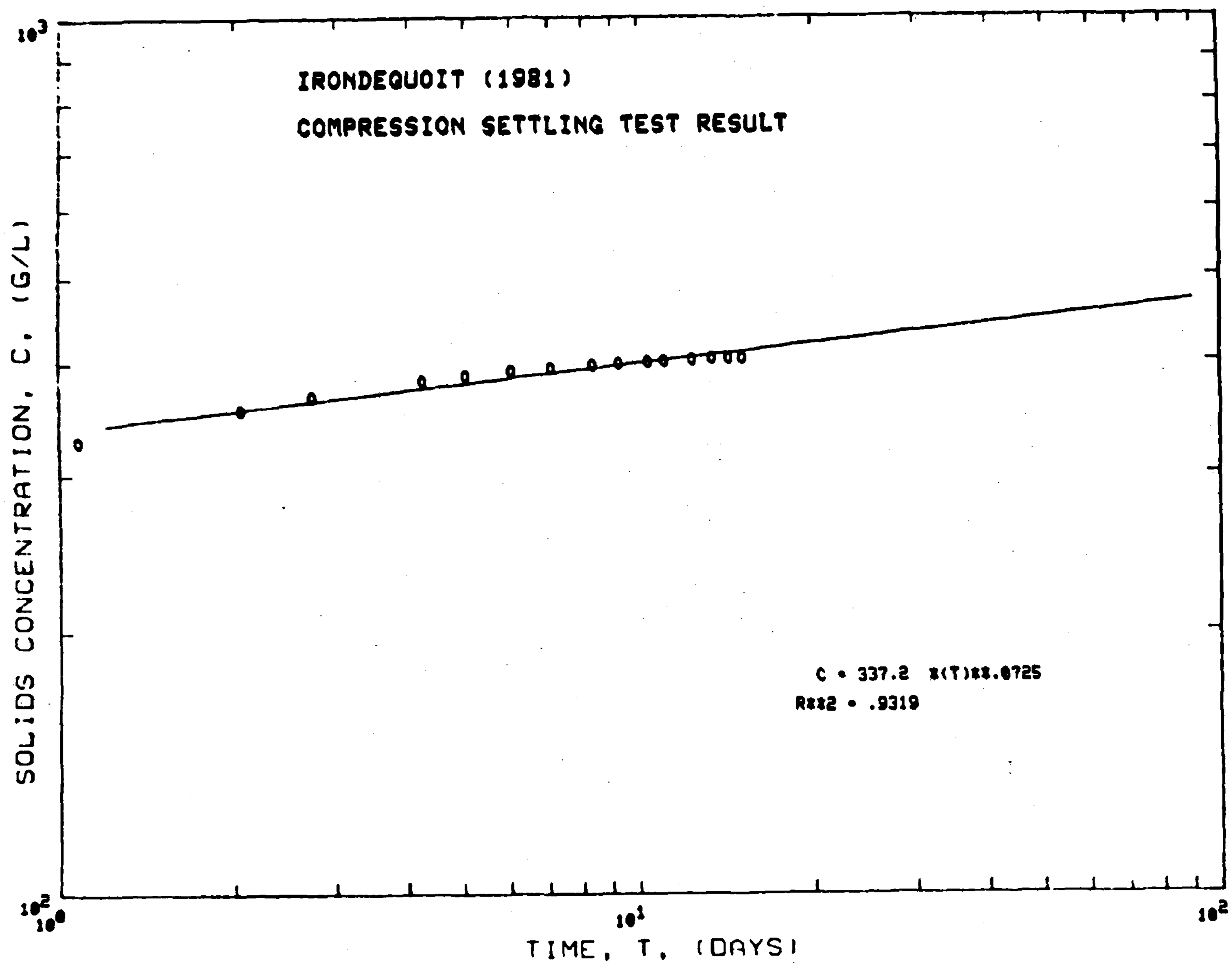

INDIANA HARBOR (63 G/L - 1979)
INITIAL SUPERNATANT (G/L) = 63.
TSS, (G/L)
RETENTION TIME, (HRS)
0
5
10
15
20
25
0
2
4
6
8
10



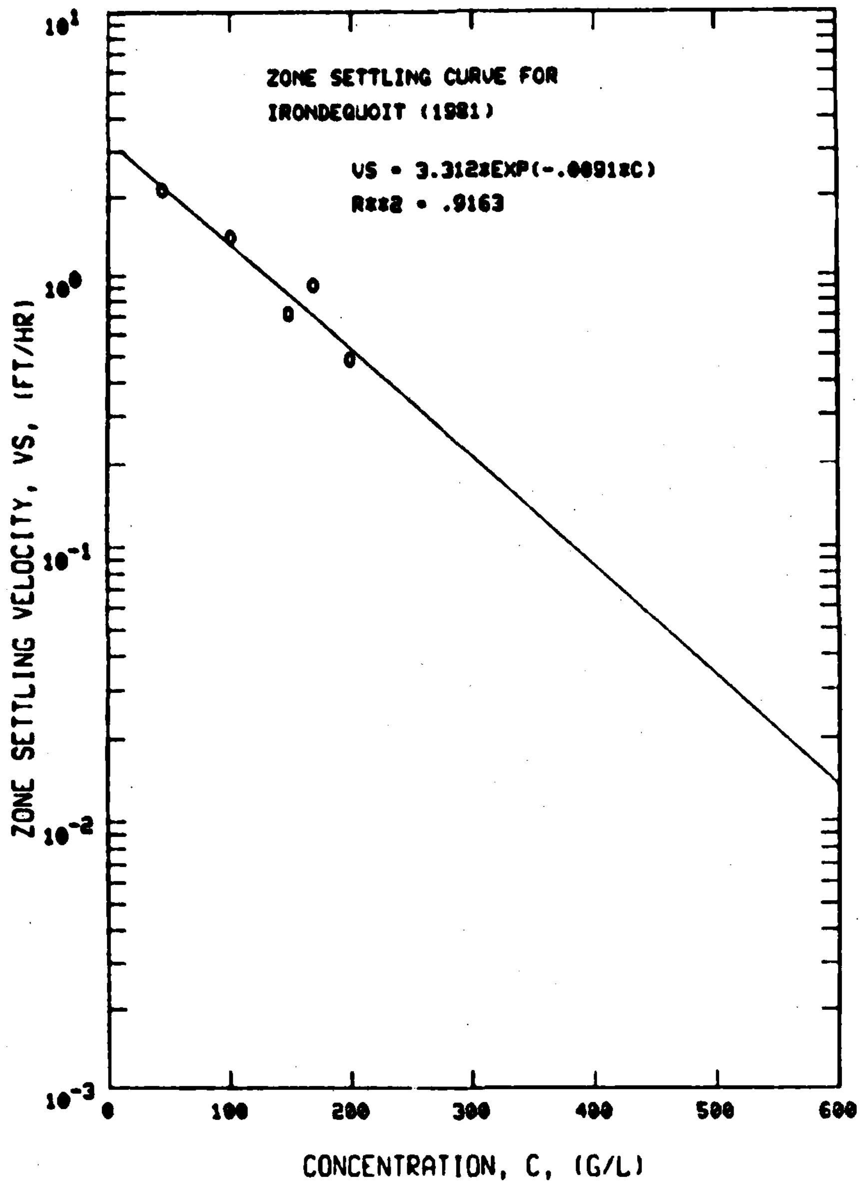
INDIANA HARBOR (1984)
COMPRESSION SETTLING TEST RESULT
C = 278. *(T)**.1262
R**2 = .9964
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)
10^0
10^1
10^2
10^2
10^3

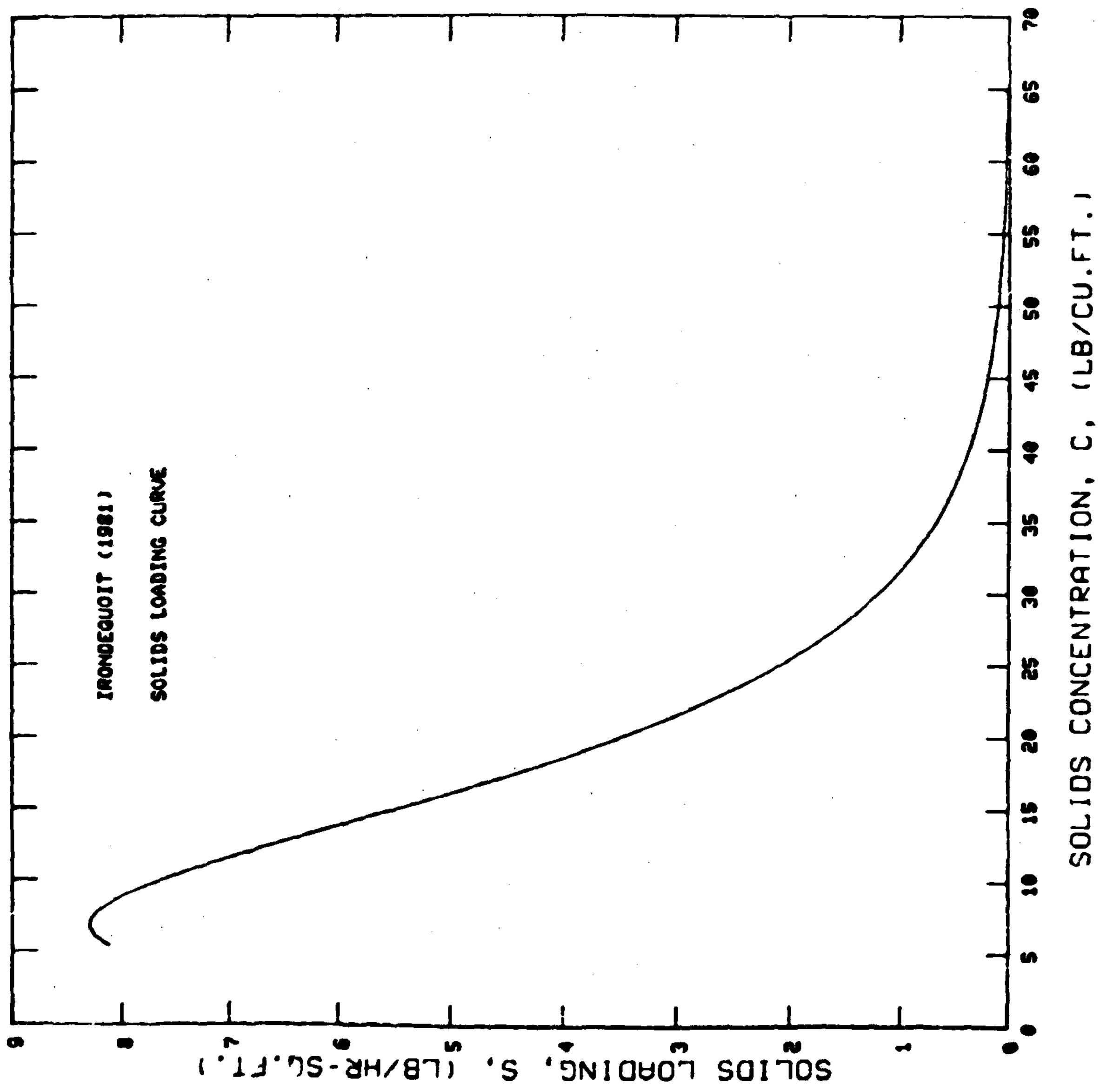

INDIANA HARBOR (100 G/L - 1984)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
4
10
20
30
40
50
60
70
80
90
100


INDIANA HARBOR (100 G/L - 1984)
INITIAL SUPERNATANT (G/L) = 100.
TSS, (G/L)
RETENTION TIME, (HRS)
0
15
30
45
60
75
0
70
140
210
280
350

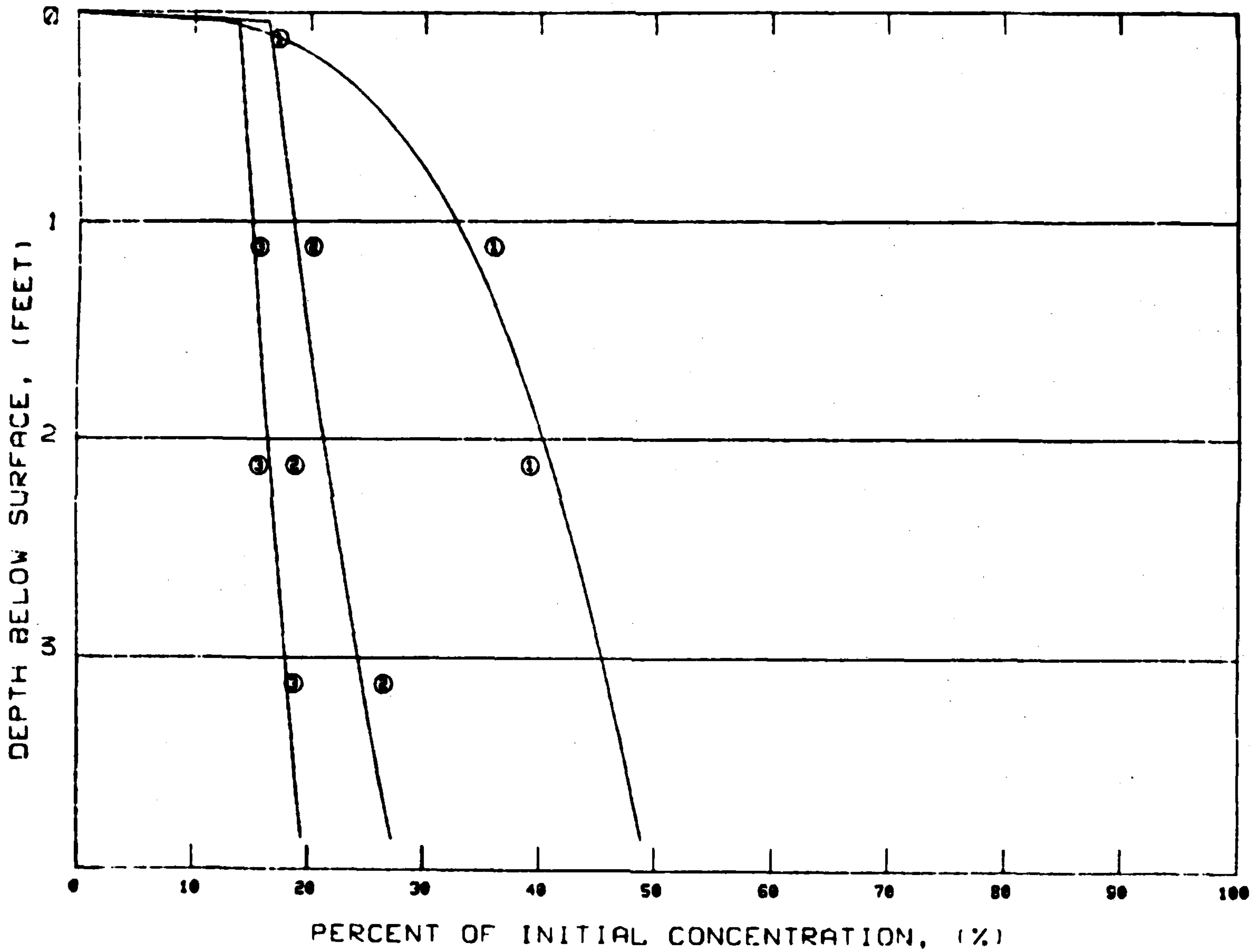


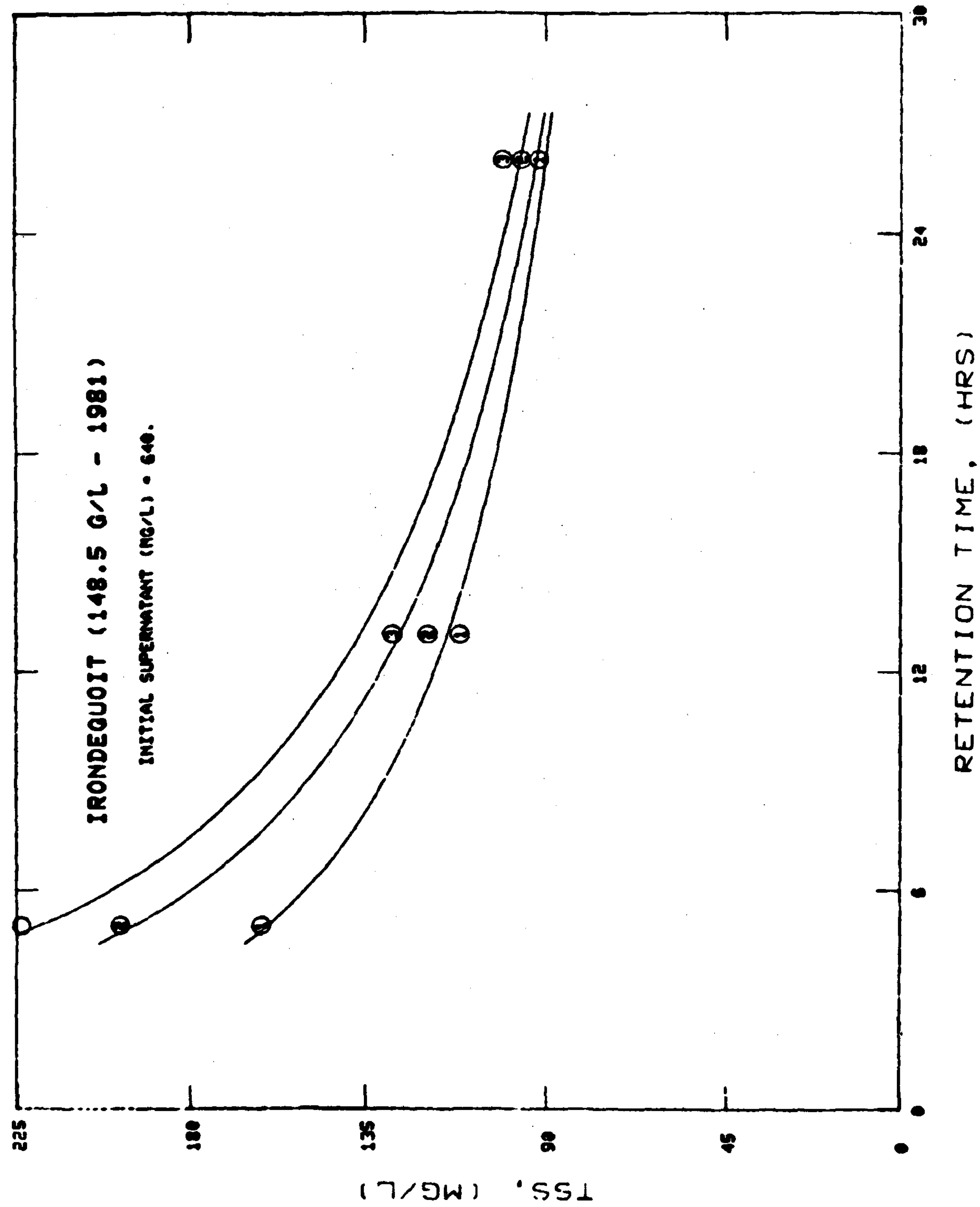
IRONDEQUOIT (1981)
COMPRESSION SETTLING TEST RESULT
C = 337.2 *(T)**.0725
R**2 = .9319
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)

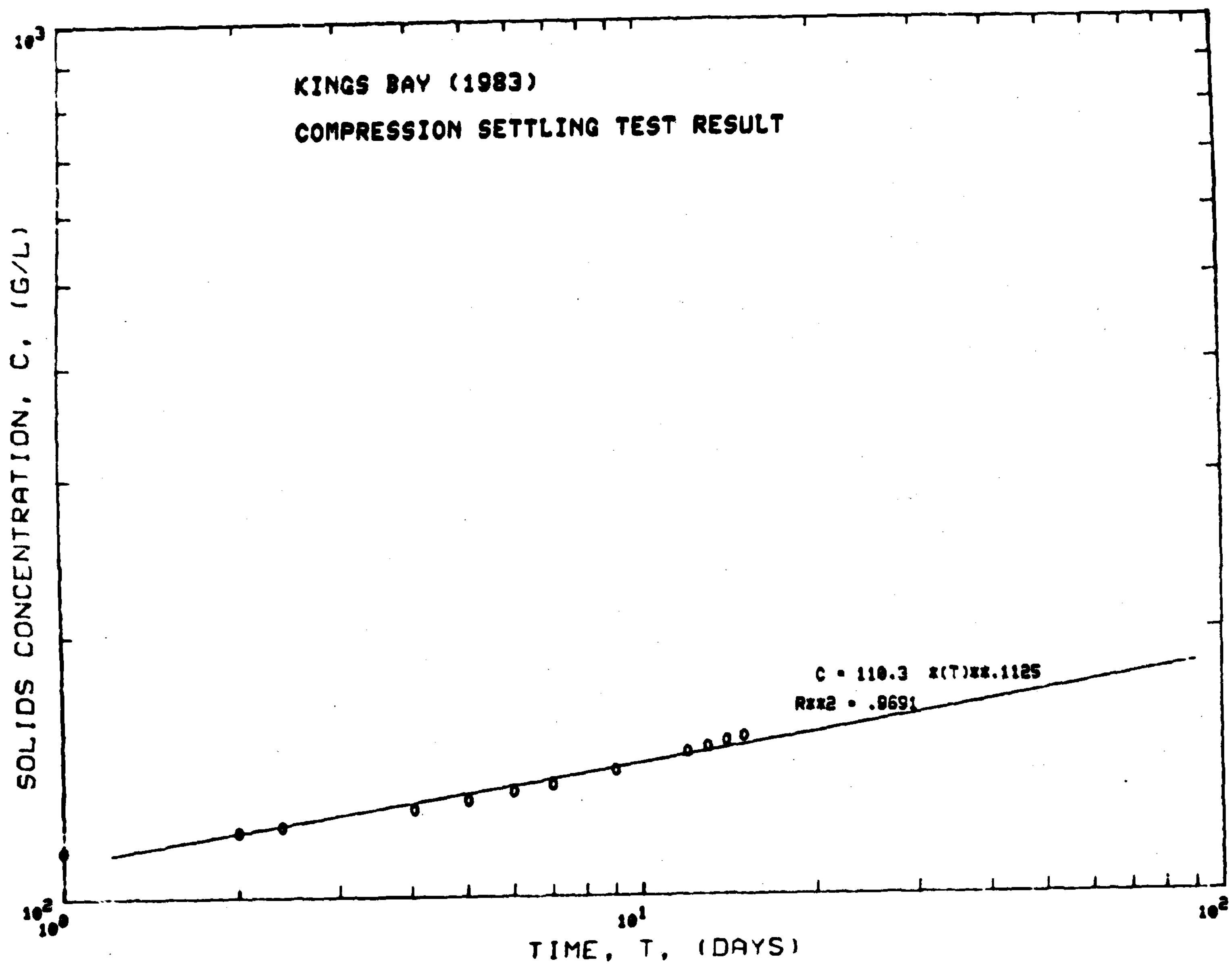

ZONE SETTLING CURVE FOR
IRONDEQUOIT (1981)
VS = 3.312*EXP(-.0091*C)
R**2 = .9163
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

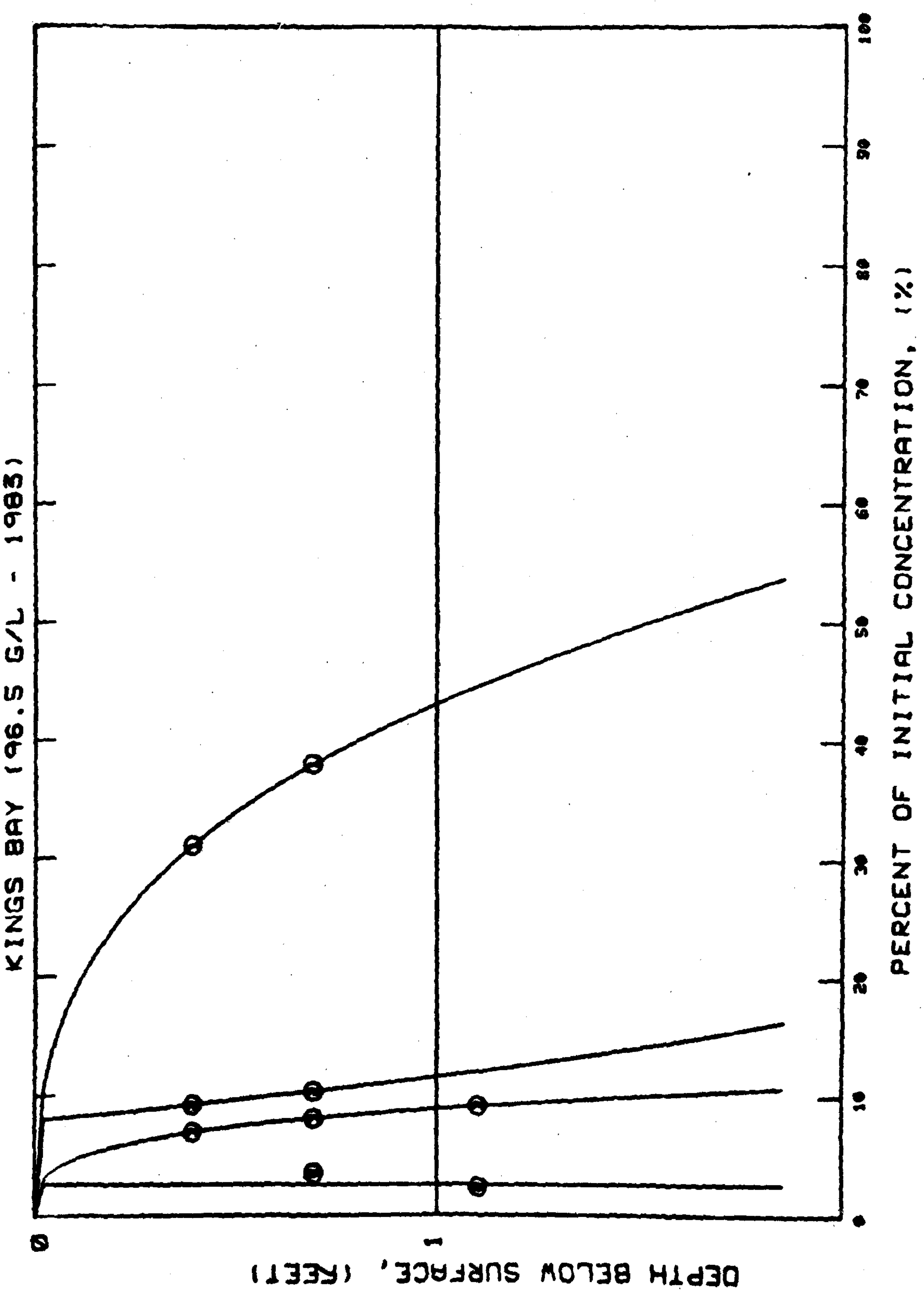

IRONDEQUOIT (1981)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
1
2
3
4
5
6
7
8
9

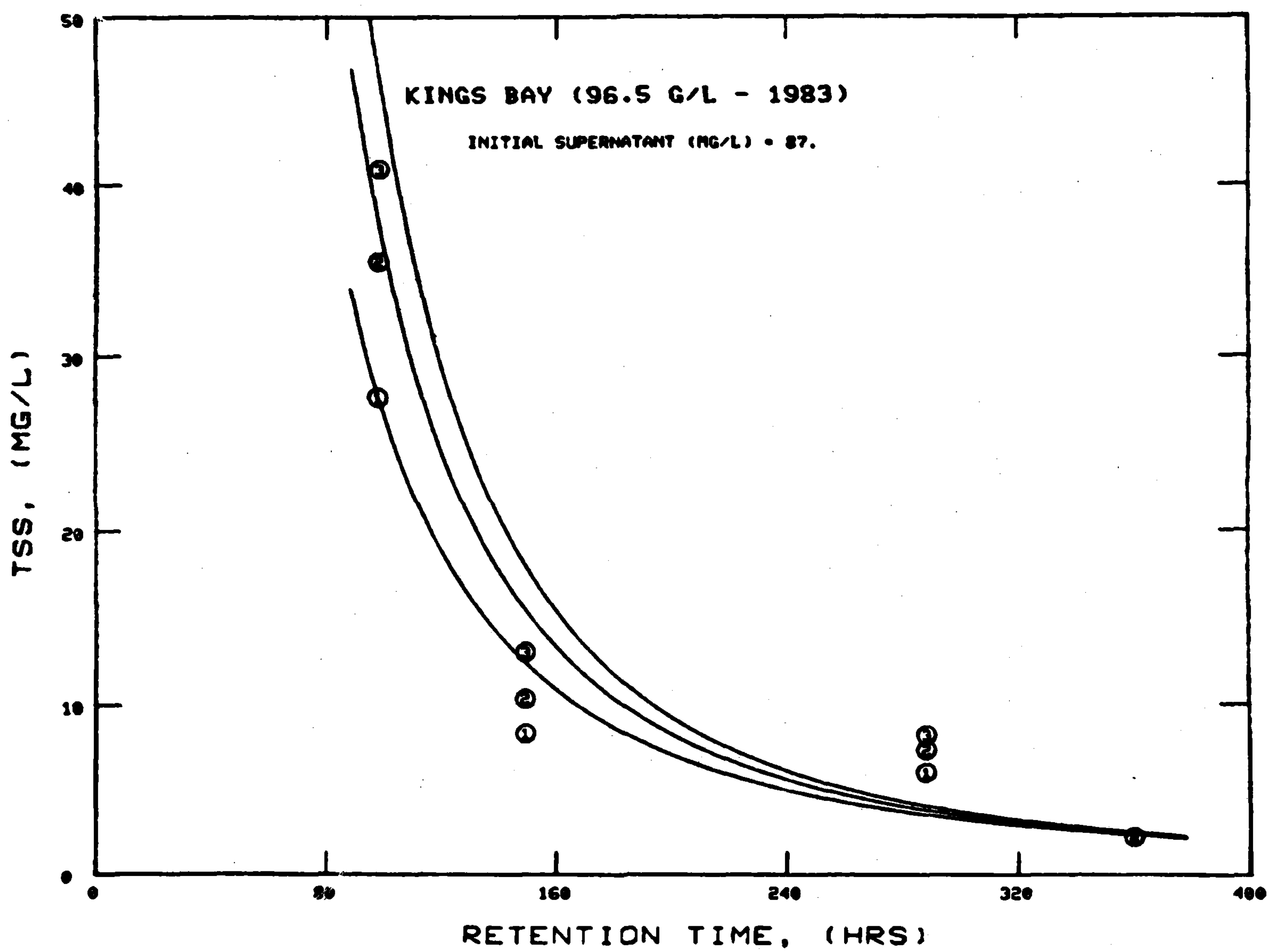
IRONDEQUOIT (148.5 G/L - 1981)

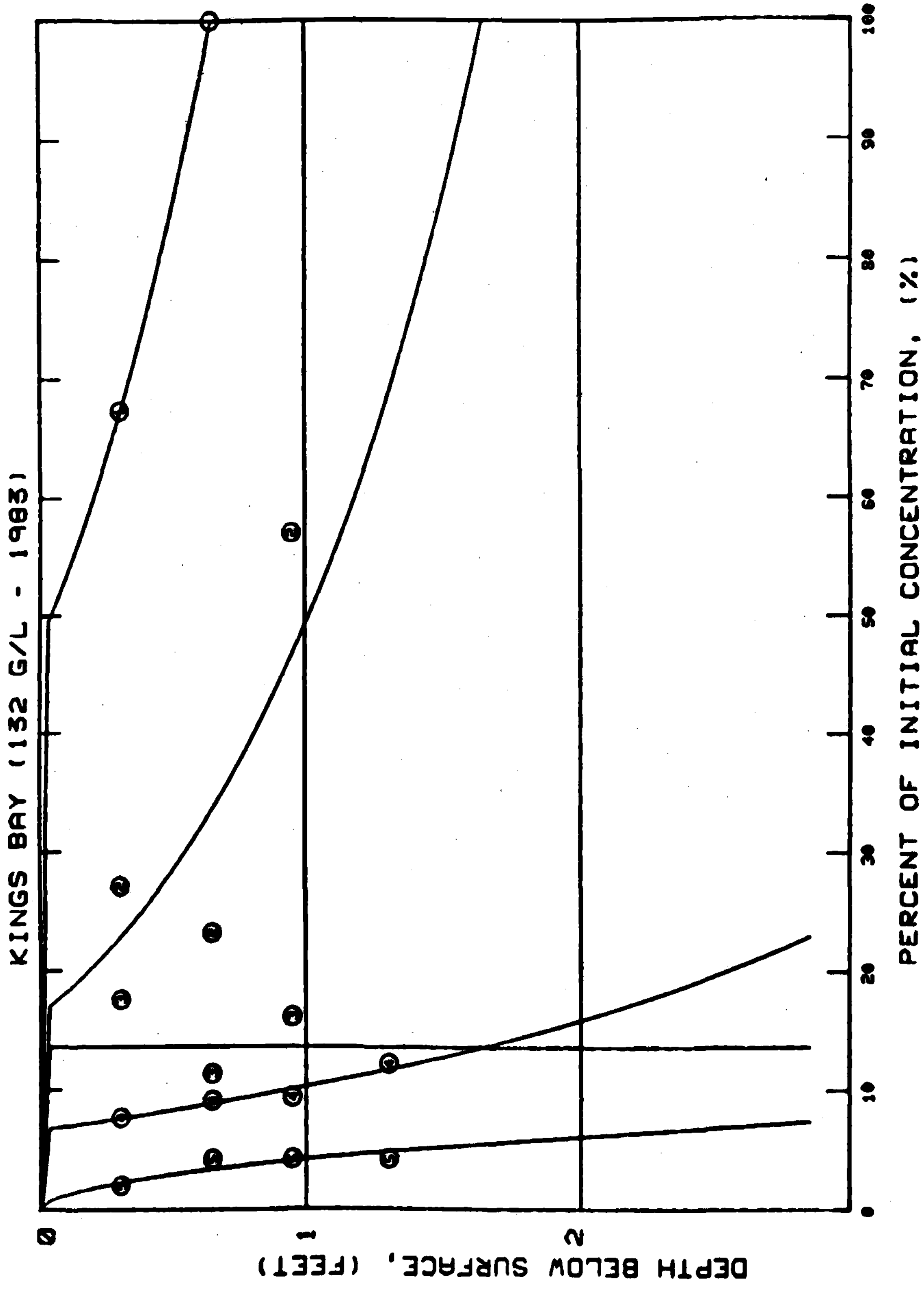



IRONDEQUOIT (148.5 G/L - 1981)
INITIAL SUPERNATANT (MG/L) = 640.
TSS, (MG/L)
225
180
135
90
45
0
6
12
18
24
30
RETENTION TIME, (HRS)

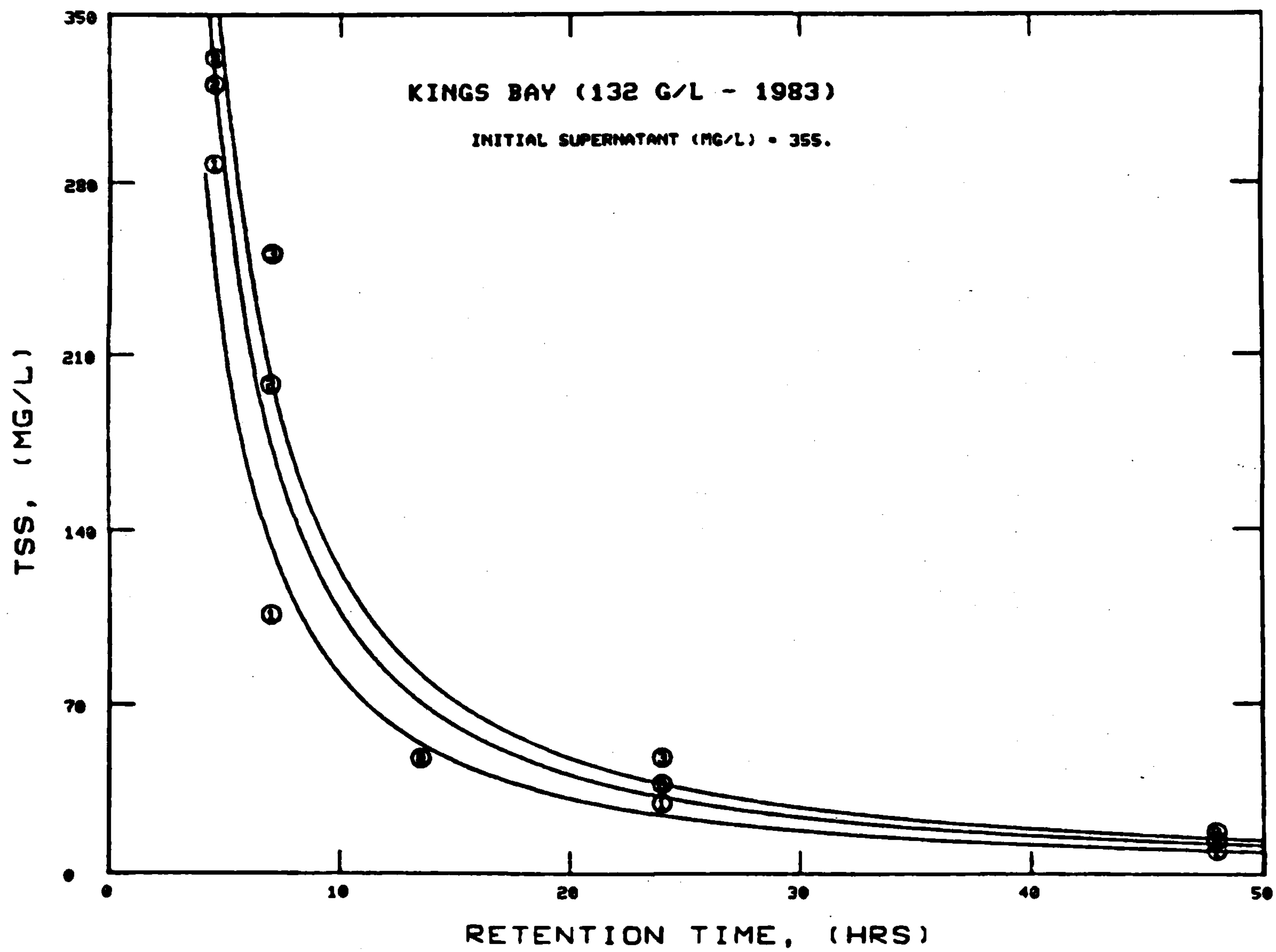

KINGS BAY (1983)
COMPRESSION SETTLING TEST RESULT
C = 110.3 *(T)**.1125
R**2 = .9691
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2


KINGS BAY (96.5 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
0
10
20
30
40
50
60
70
80
90
100
DEPTH BELOW SURFACE, (FEET)
0
1

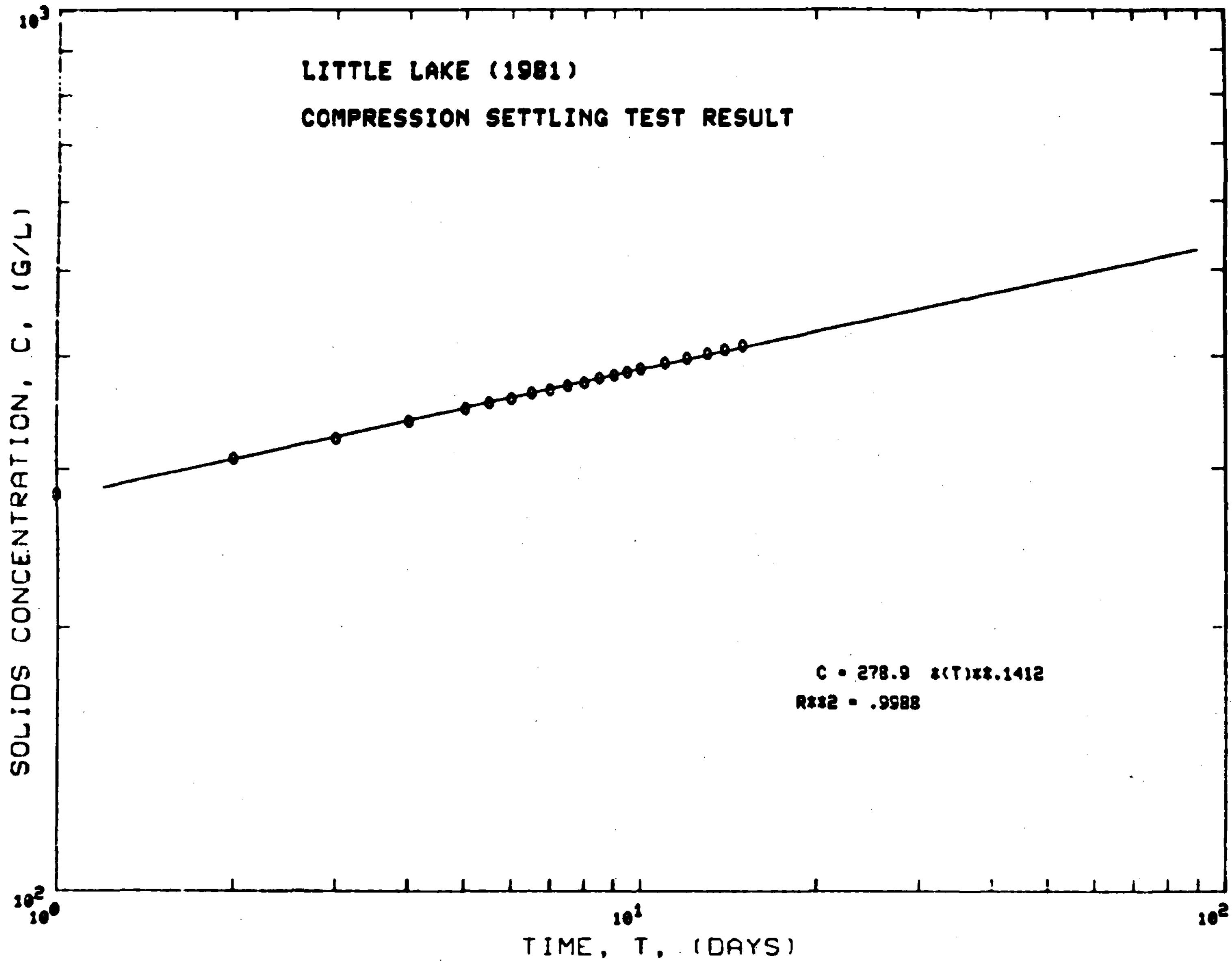

KINGS BAY (96.5 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 87.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
10
20
30
40
50
0
80
160
240
320
400

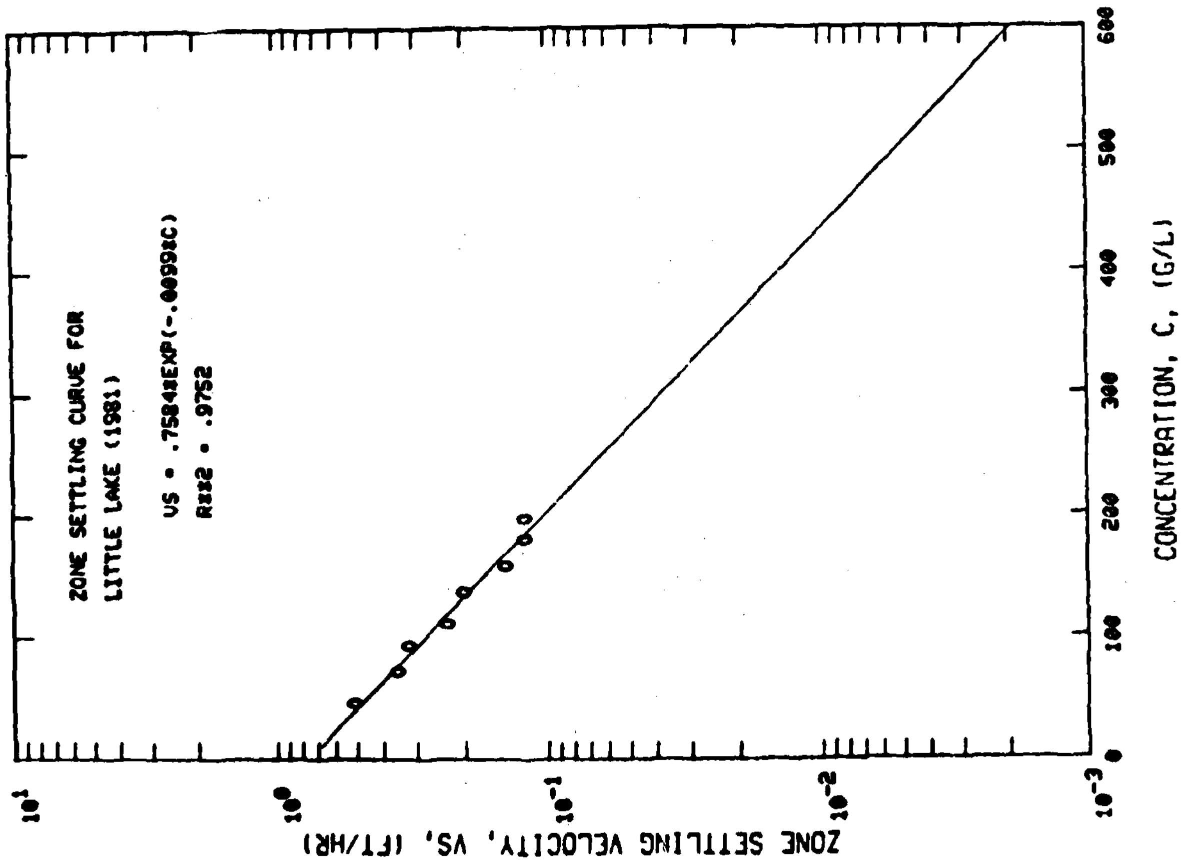


KINGS BAY (132 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2

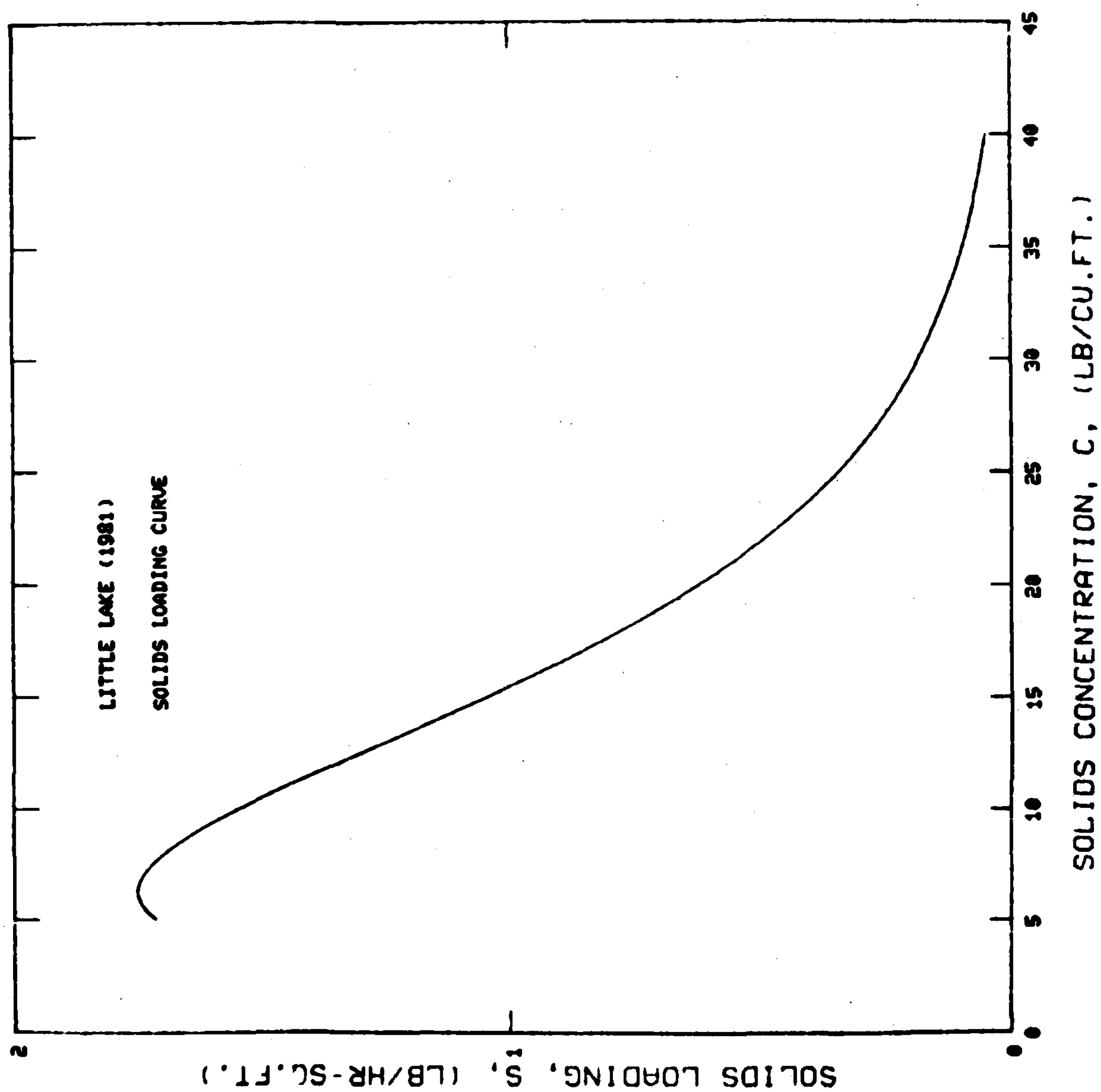


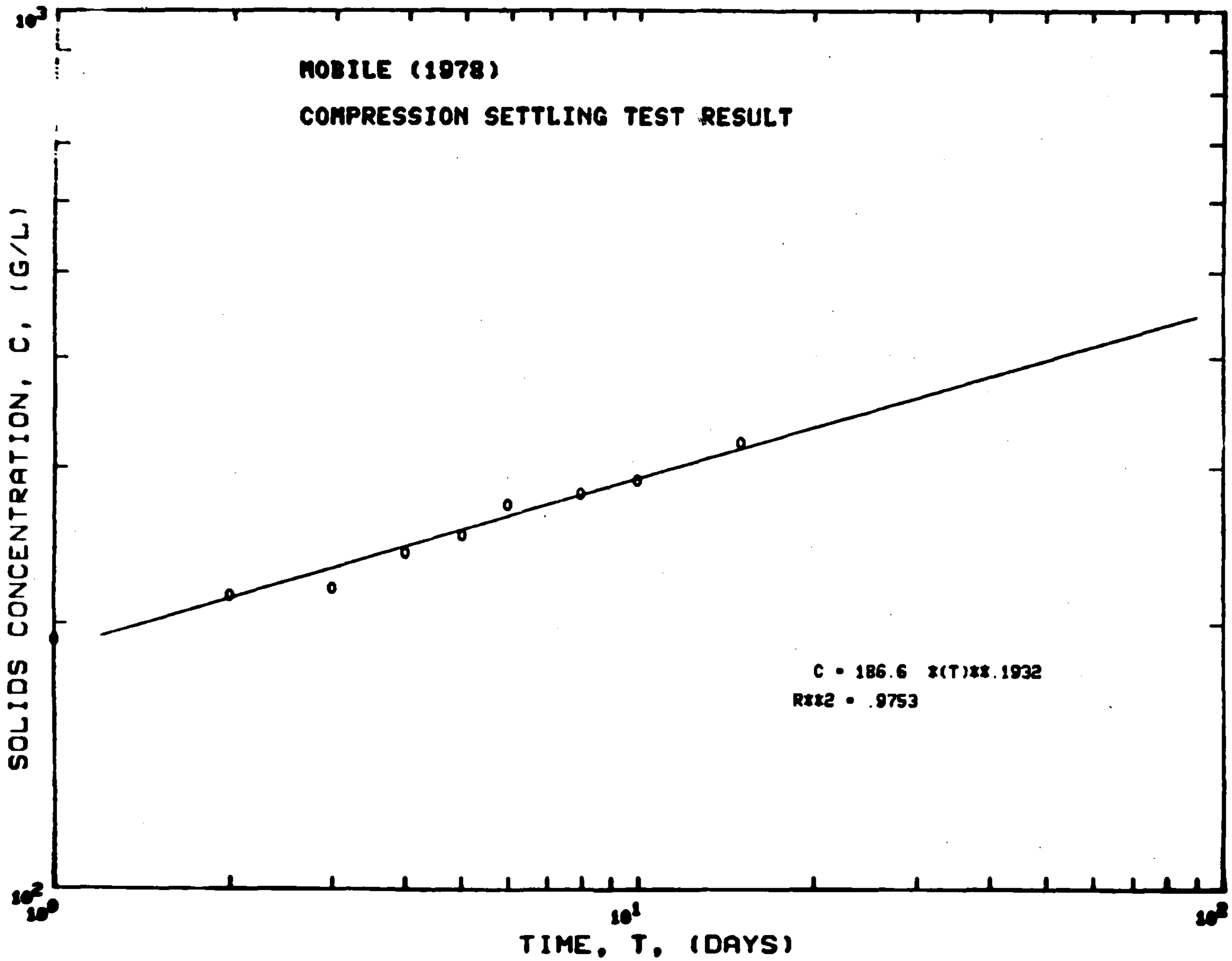
KINGS BAY (132 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 355.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
70
140
210
280
350
0
10
20
30
40
50


LITTLE LAKE (1981)
COMPRESSION SETTLING TEST RESULT
C = 278.9 *(T)**.1412
R**2 = .9988
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2

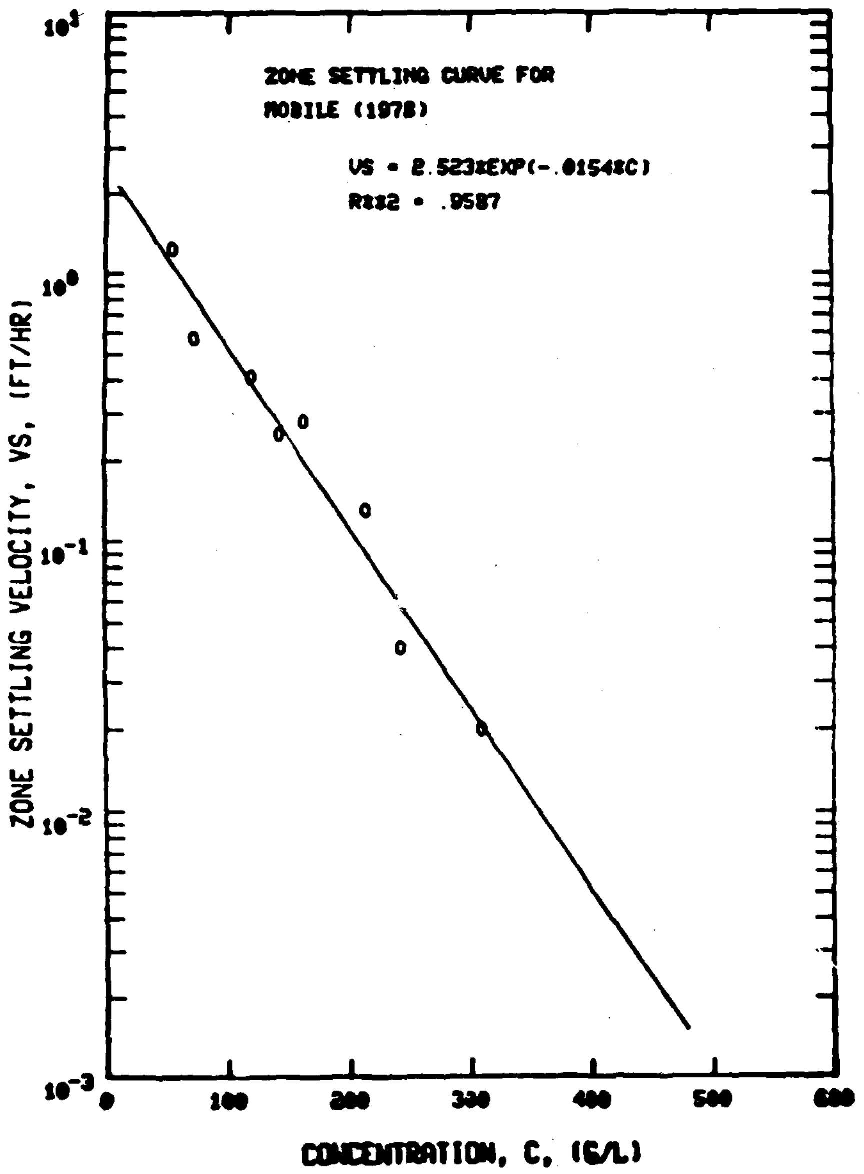


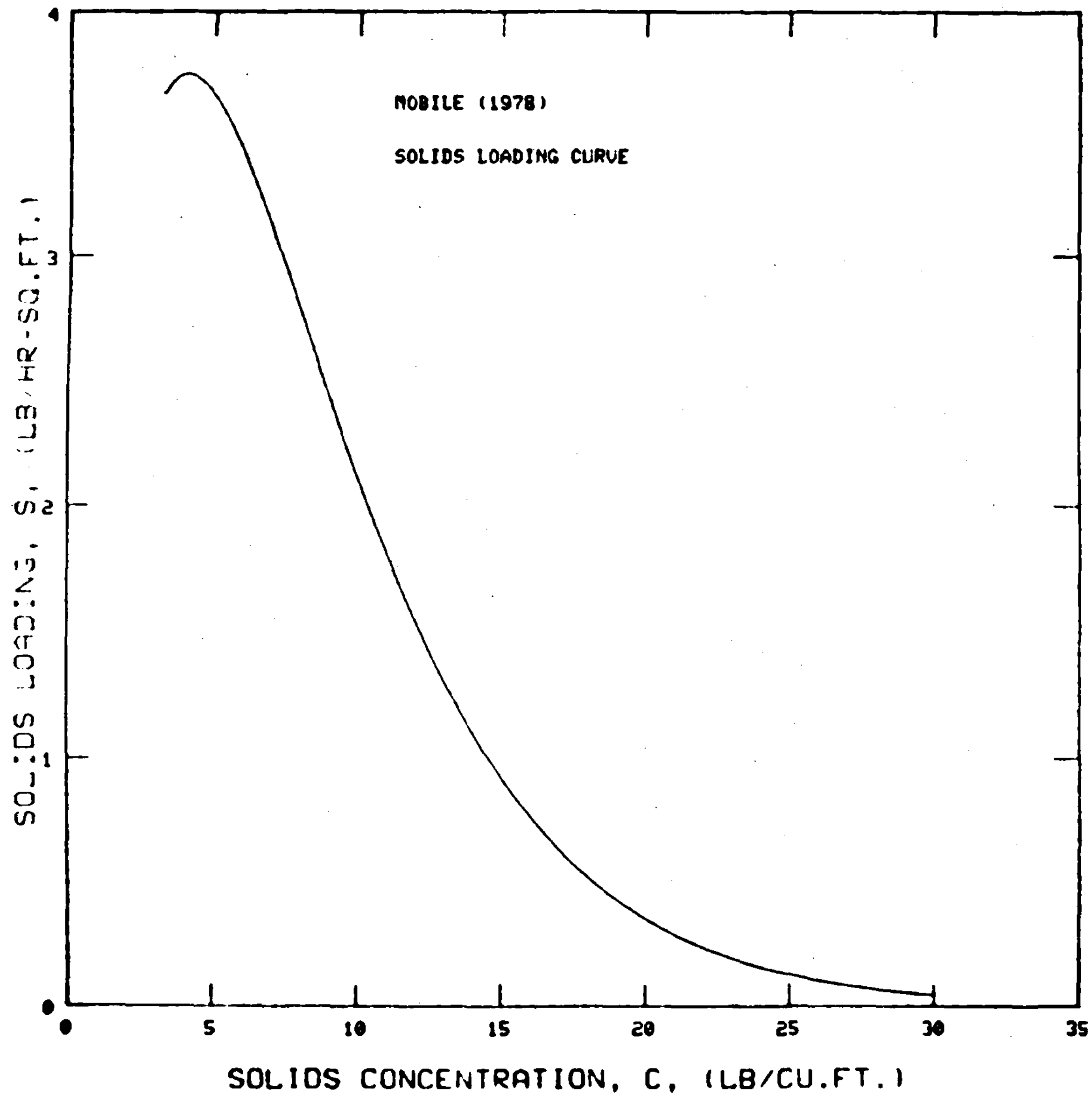
ZONE SETTLING CURVE FOR
LITTLE LAKE (1981)
VS = .7584*EXP(-.0099*C)
R**2 = .9752
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)


LITTLE LAKE (1981)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
35
40
45
0
1
2

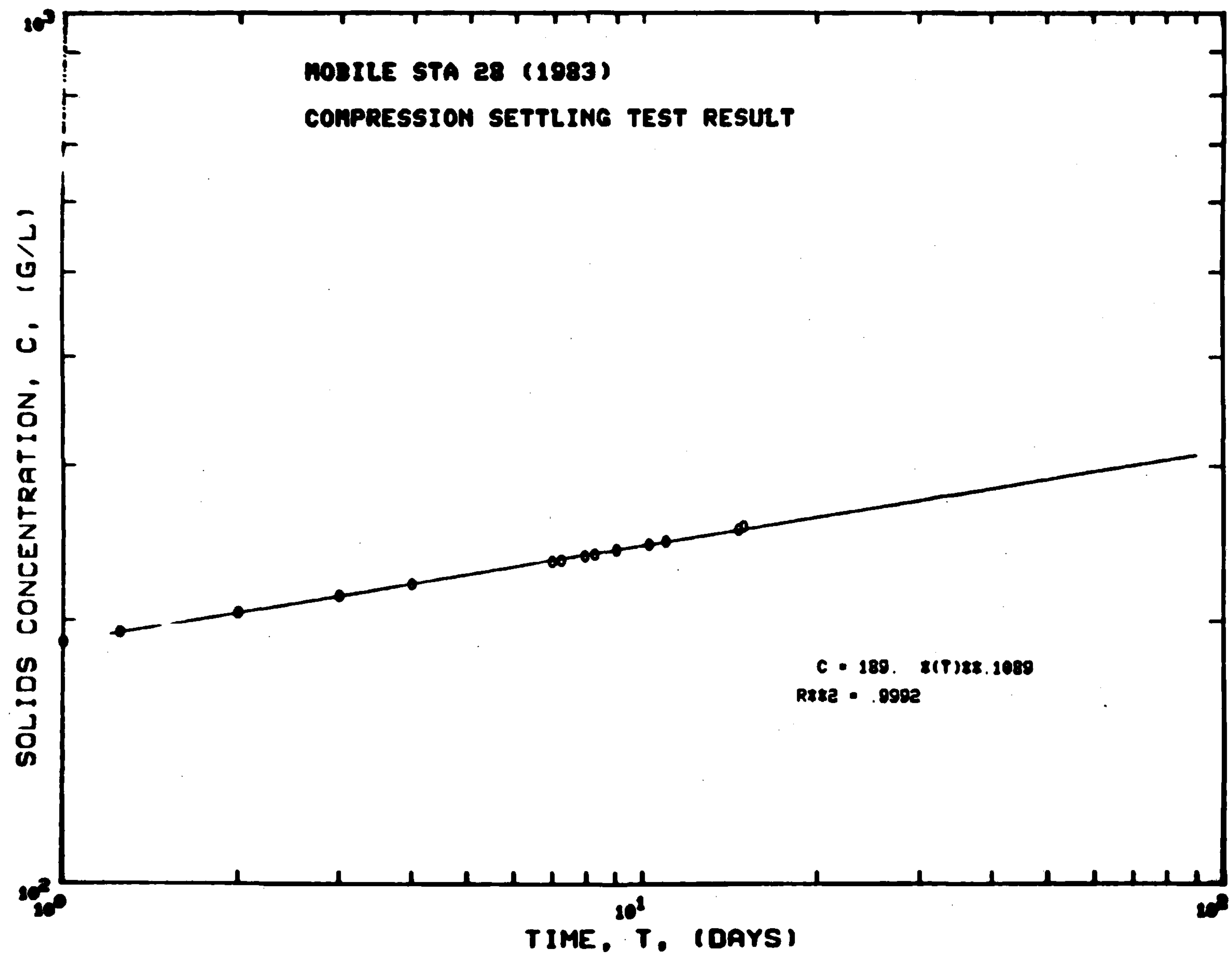


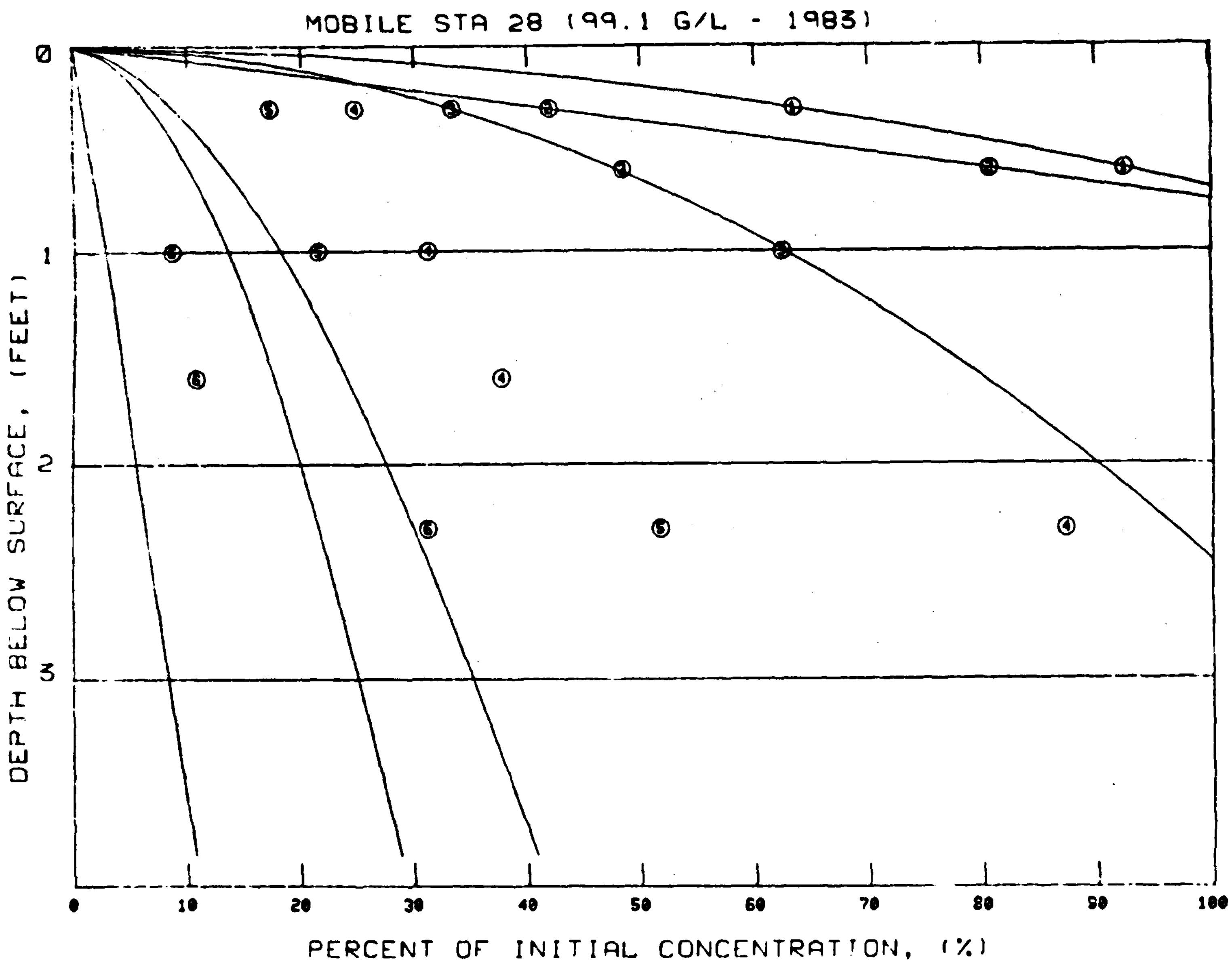
MOBILE (1978)
COMPRESSION SETTLING TEST RESULT
C = 186.6 *(T)**.1932
R**2 = .9753
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10³
10²
10⁰
10¹
10²

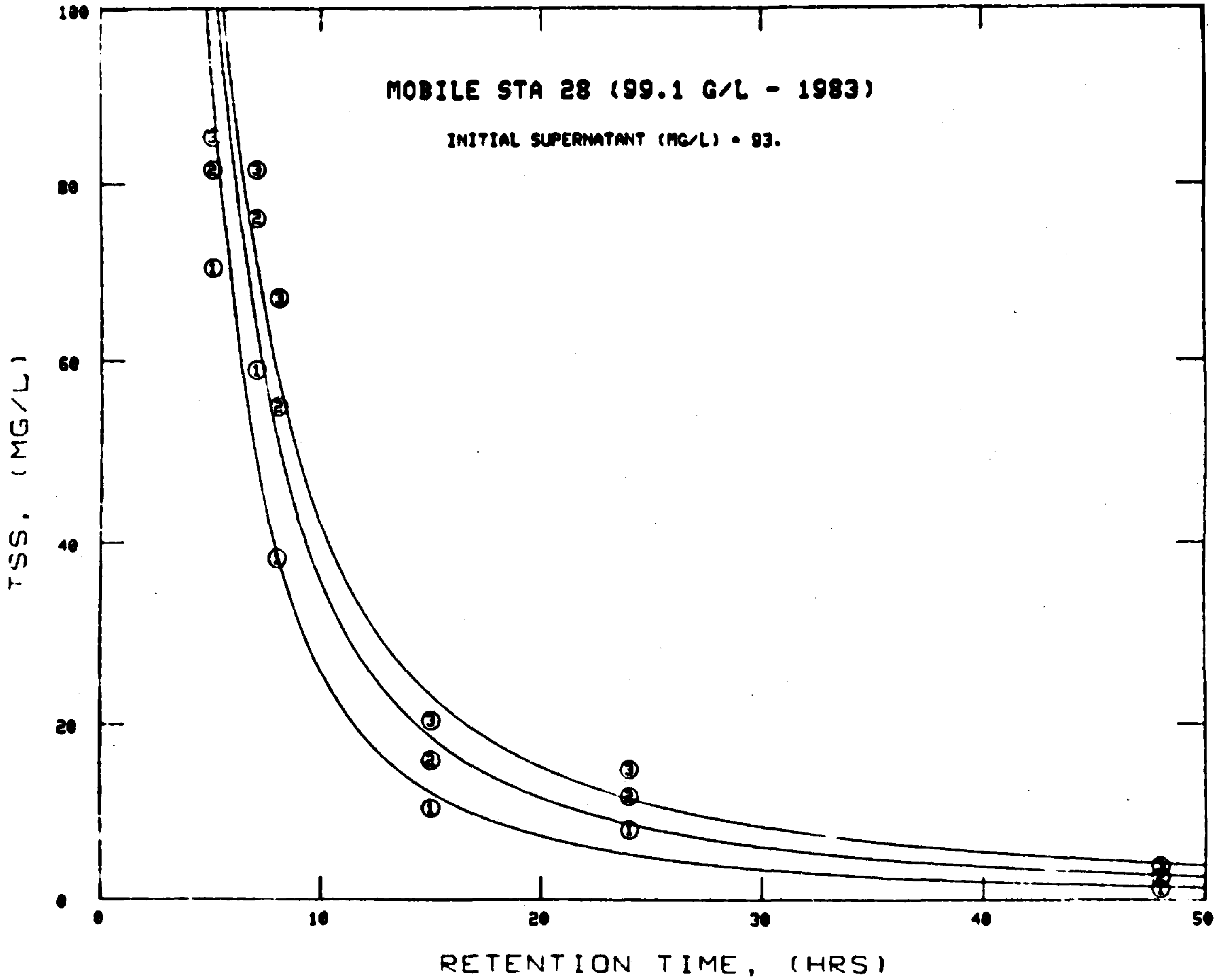

ZONE SETTLING CURVE FOR
MOBILE (1978)
VS = 2.523*EXP(-.0154*C)
R**2 = .9587
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
0
100
200
300
400
500
600
10^1
10^0
10^-1
10^-2
10^-3



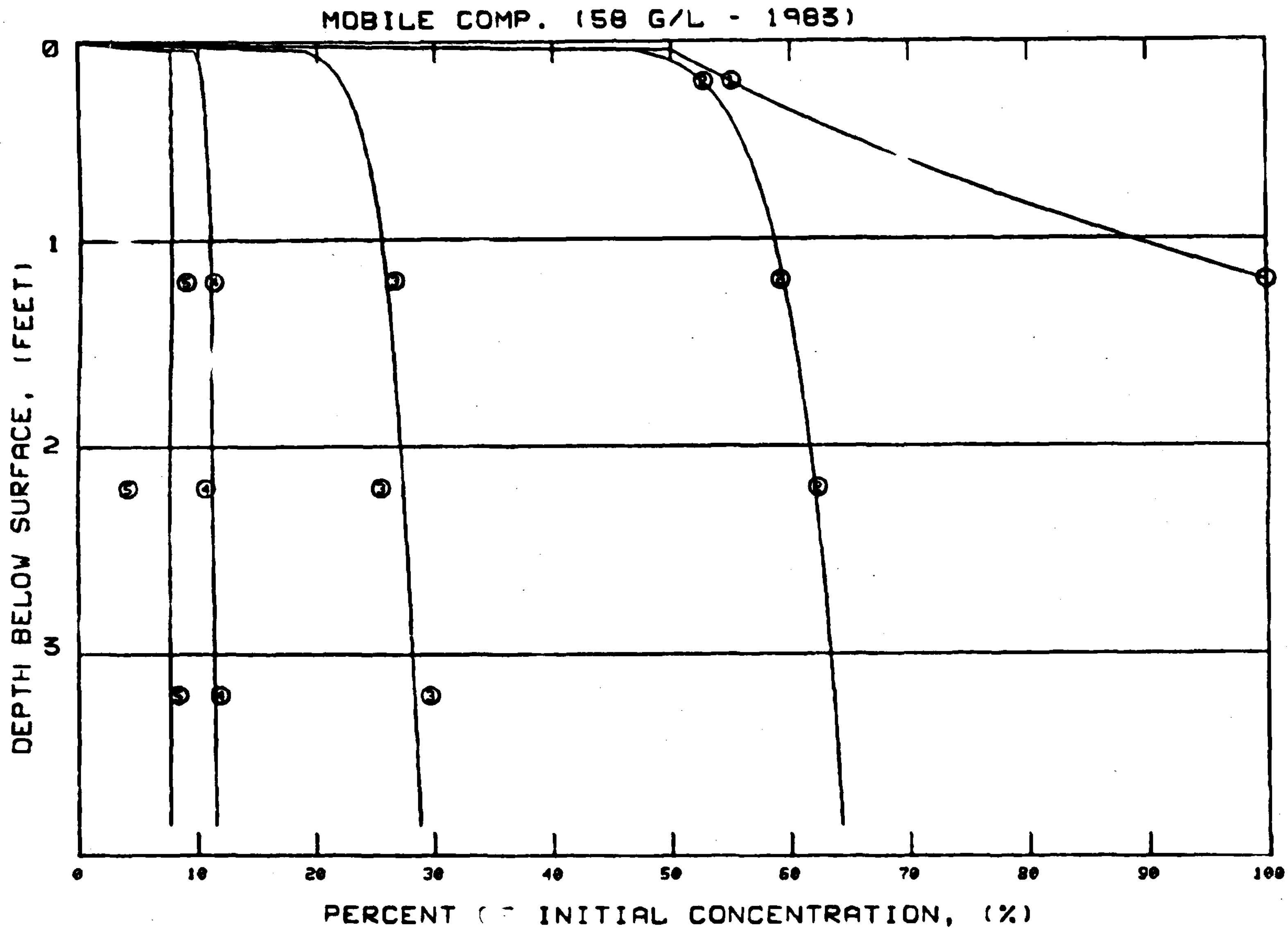
NOBILE (1978)
SOLIDS LOADING CURVE
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
1
2
3
4
0
5
10
15
20
25
30
35
SOLIDS CONCENTRATION, C, (LB/CU.FT.)


MOBILE STA 28 (1983)
COMPRESSION SETTLING TEST RESULT
C = 189. *(T)**.1089
R**2 = .9992
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2

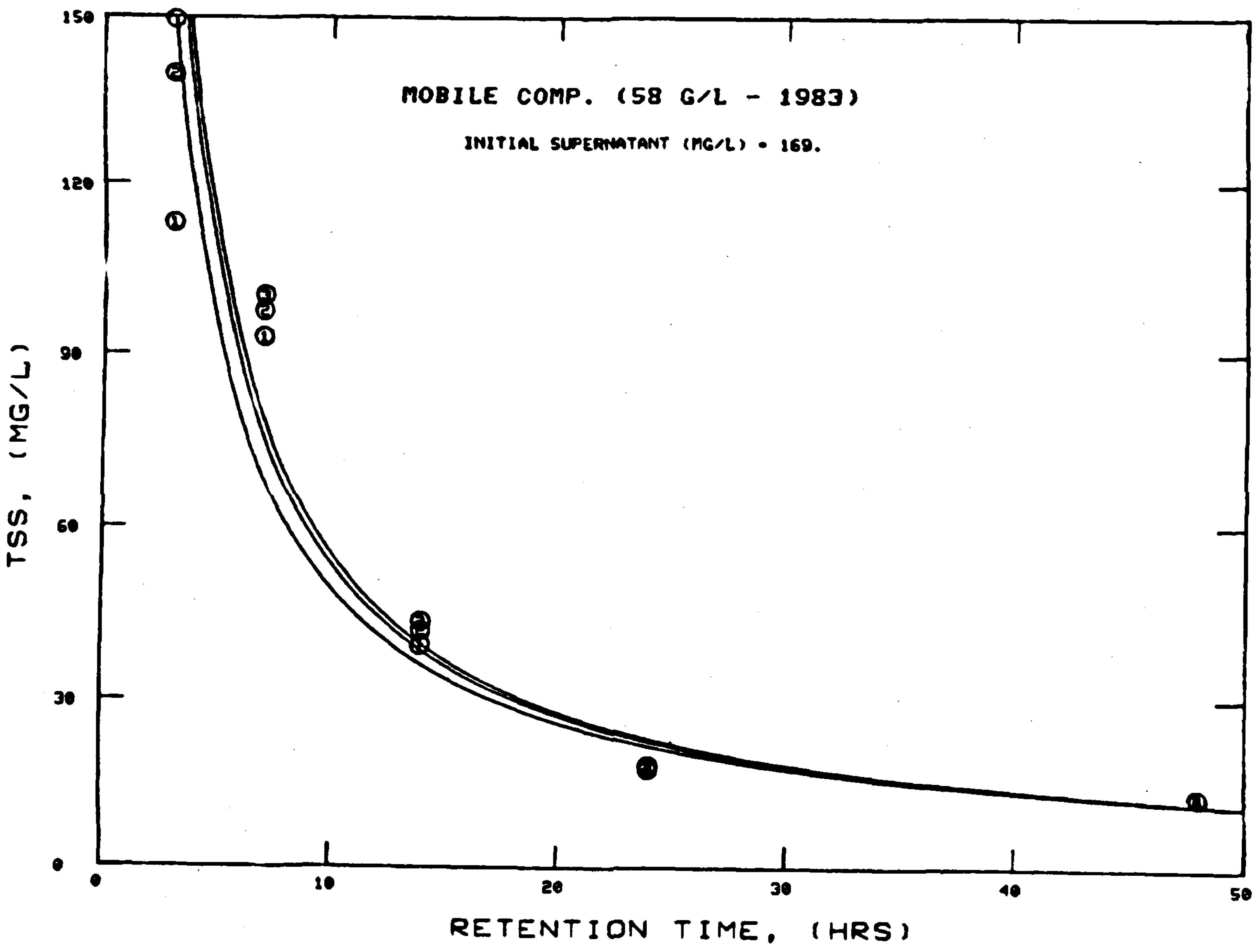

MOBILE STA 28 (99.1 G/L - 1983)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100
PERCENT OF INITIAL CONCENTRATION, (%)

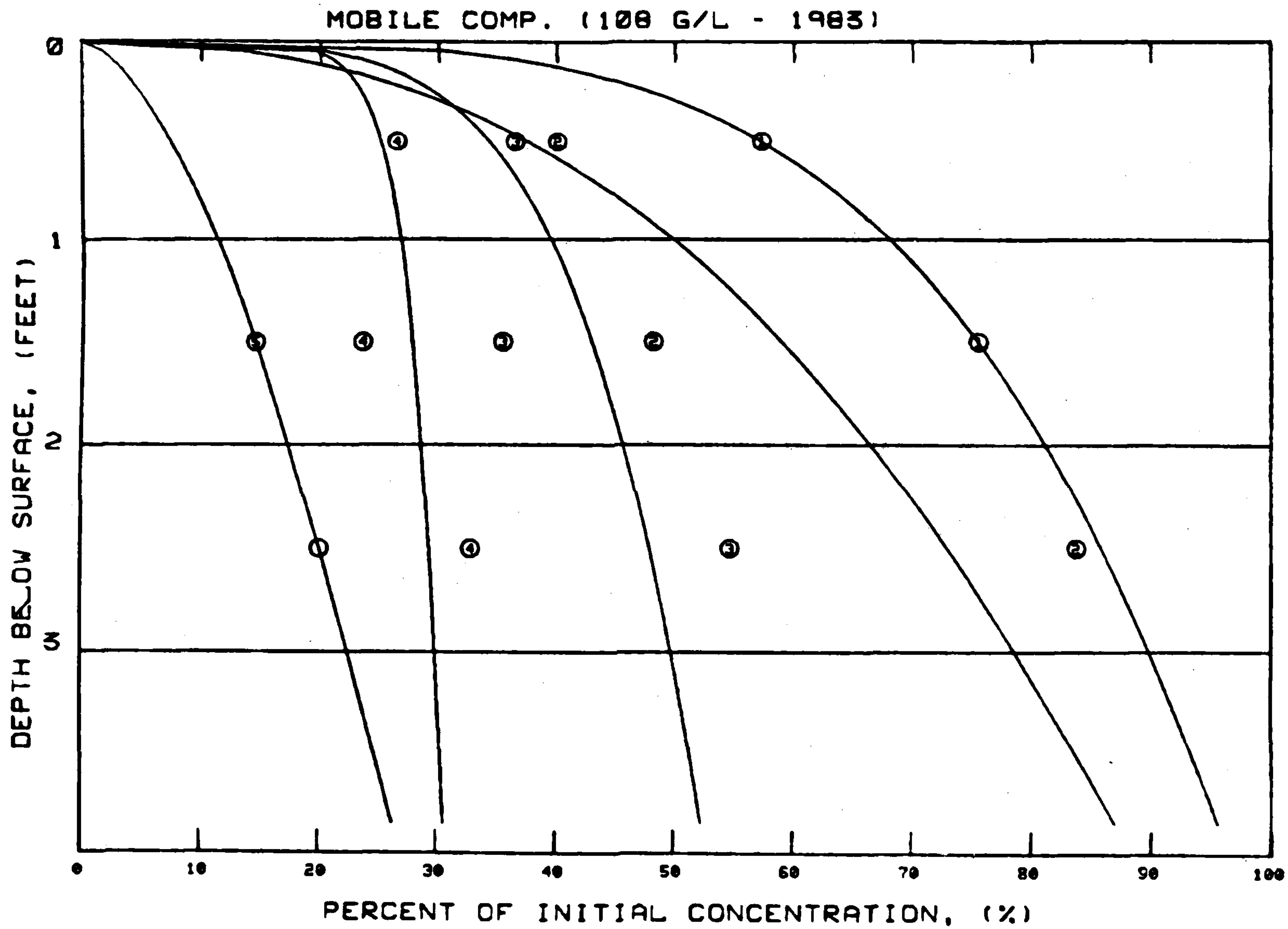


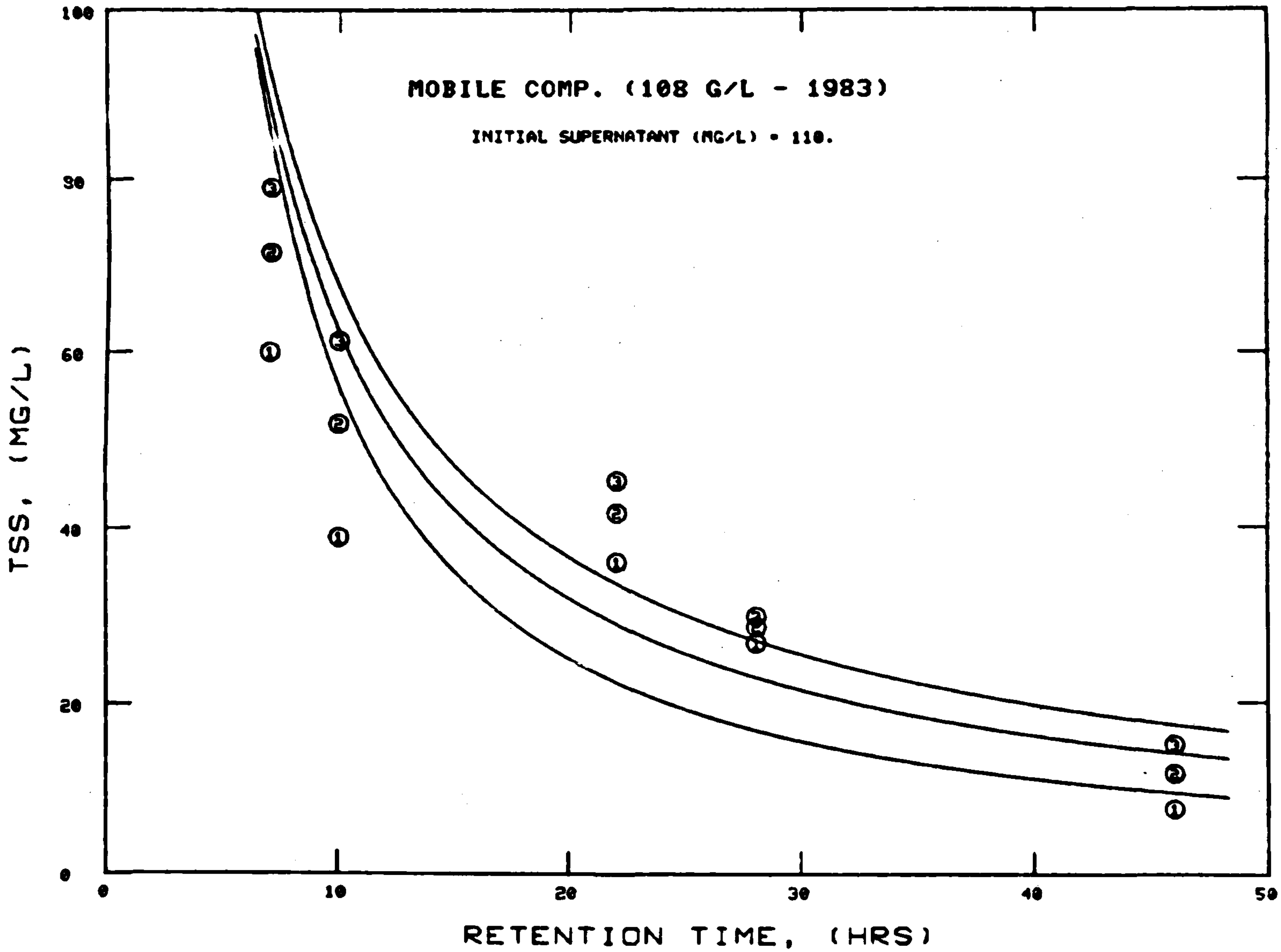
MOBILE STA 28 (99.1 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 93.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
20
40
60
80
100
0
10
20
30
40
50

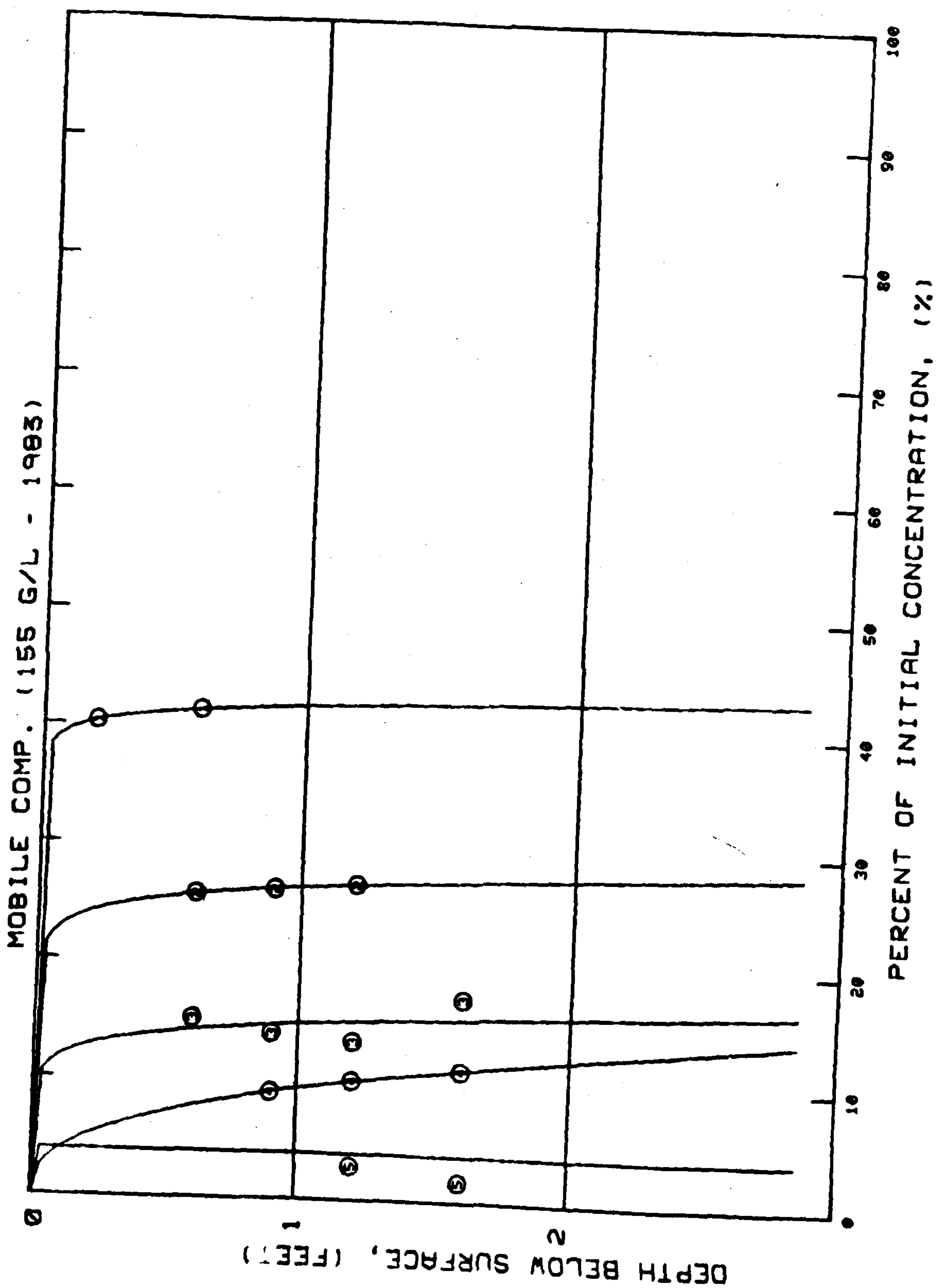


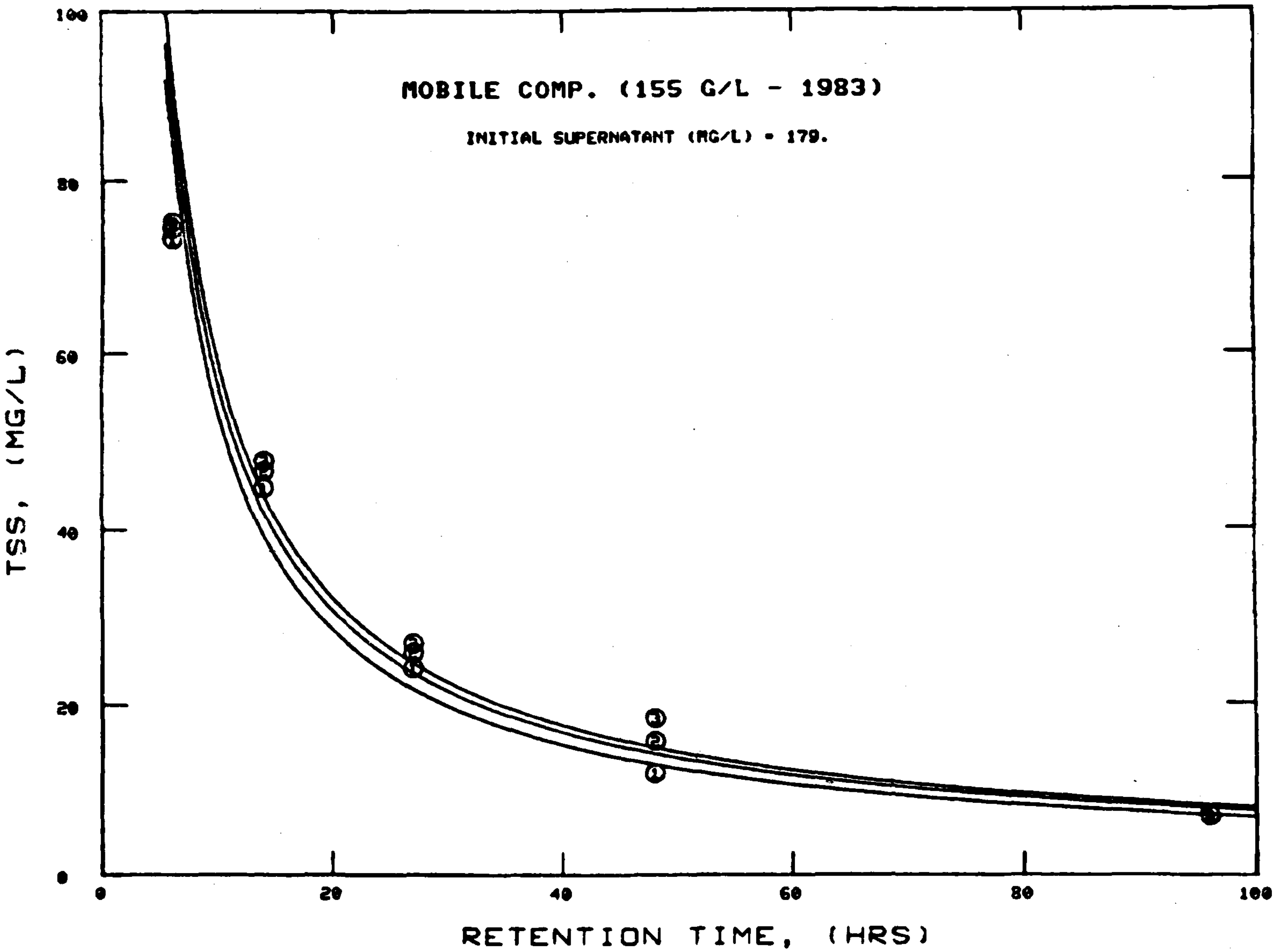
MOBILE COMP. (58 G/L - 1983)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100
PERCENT OF INITIAL CONCENTRATION, (%)

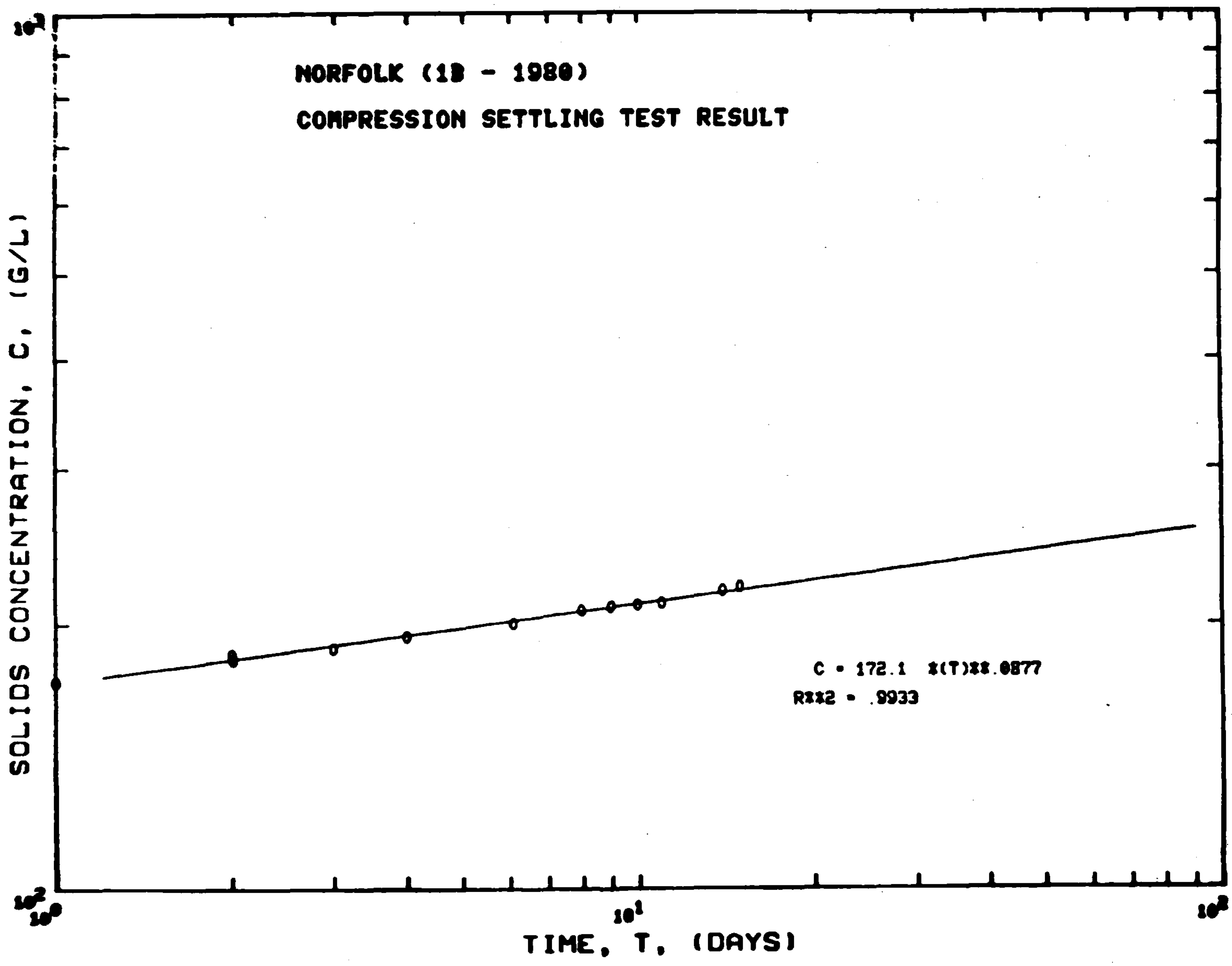

MOBILE COMP. (58 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 169.
TSS, (MG/L)
150
120
90
60
30
0
0
10
20
30
40
50
RETENTION TIME, (HRS)

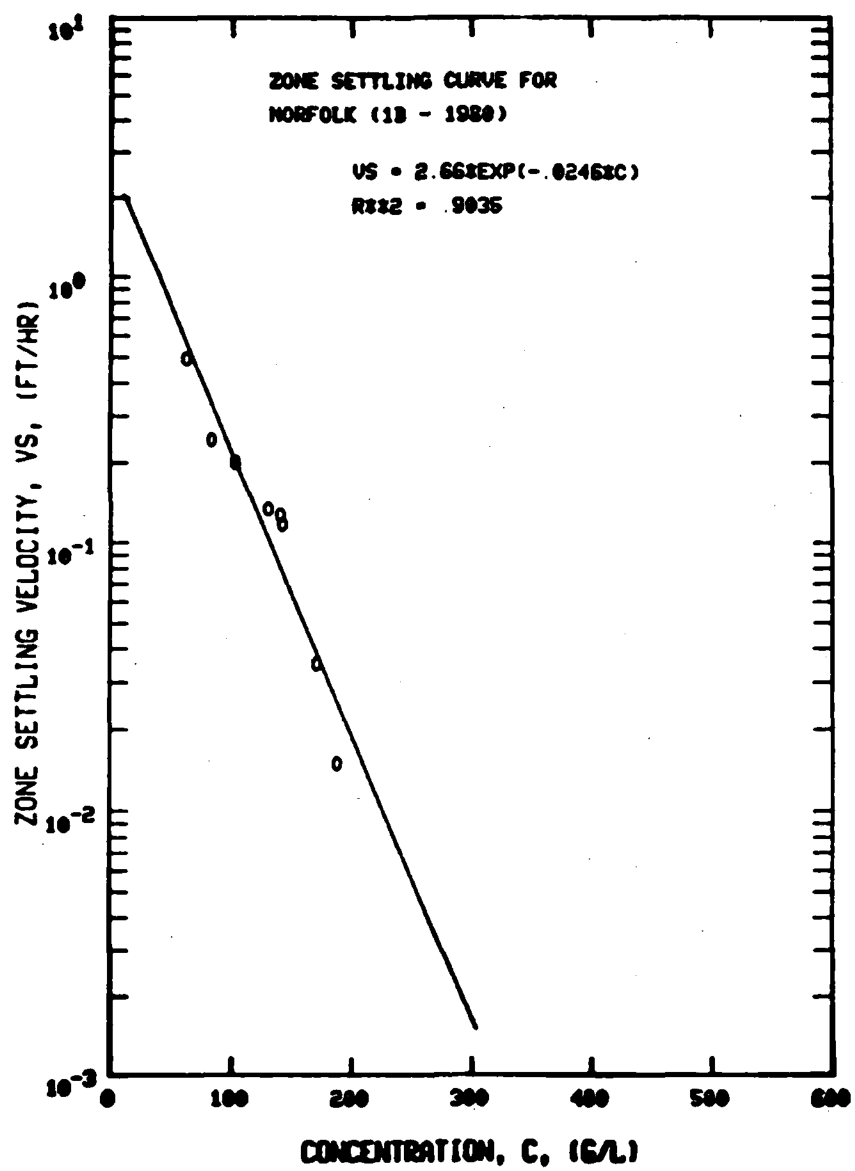

MOBILE COMP. (100 G/L - 1983)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
PERCENT OF INITIAL CONCENTRATION, (%)
0
10
20
30
40
50
60
70
80
90
100


MOBILE COMP. (108 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 110.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
20
40
60
80
100
0
10
20
30
40
50


MOBILE COMP. (155 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
1
2
0
10
20
30
40
50
60
70
80
90
100


MOBILE COMP. (155 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 179.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
20
40
60
80
100


NORFOLK (1B - 1980)
COMPRESSION SETTLING TEST RESULT
C = 172.1 *(T)**.0877
R**2 = .9933
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2


ZONE SETTLING CURVE FOR
NORFOLK (13 - 1980)
VS = 2.66*EXP(-.0246*C)
R**2 = .9035
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

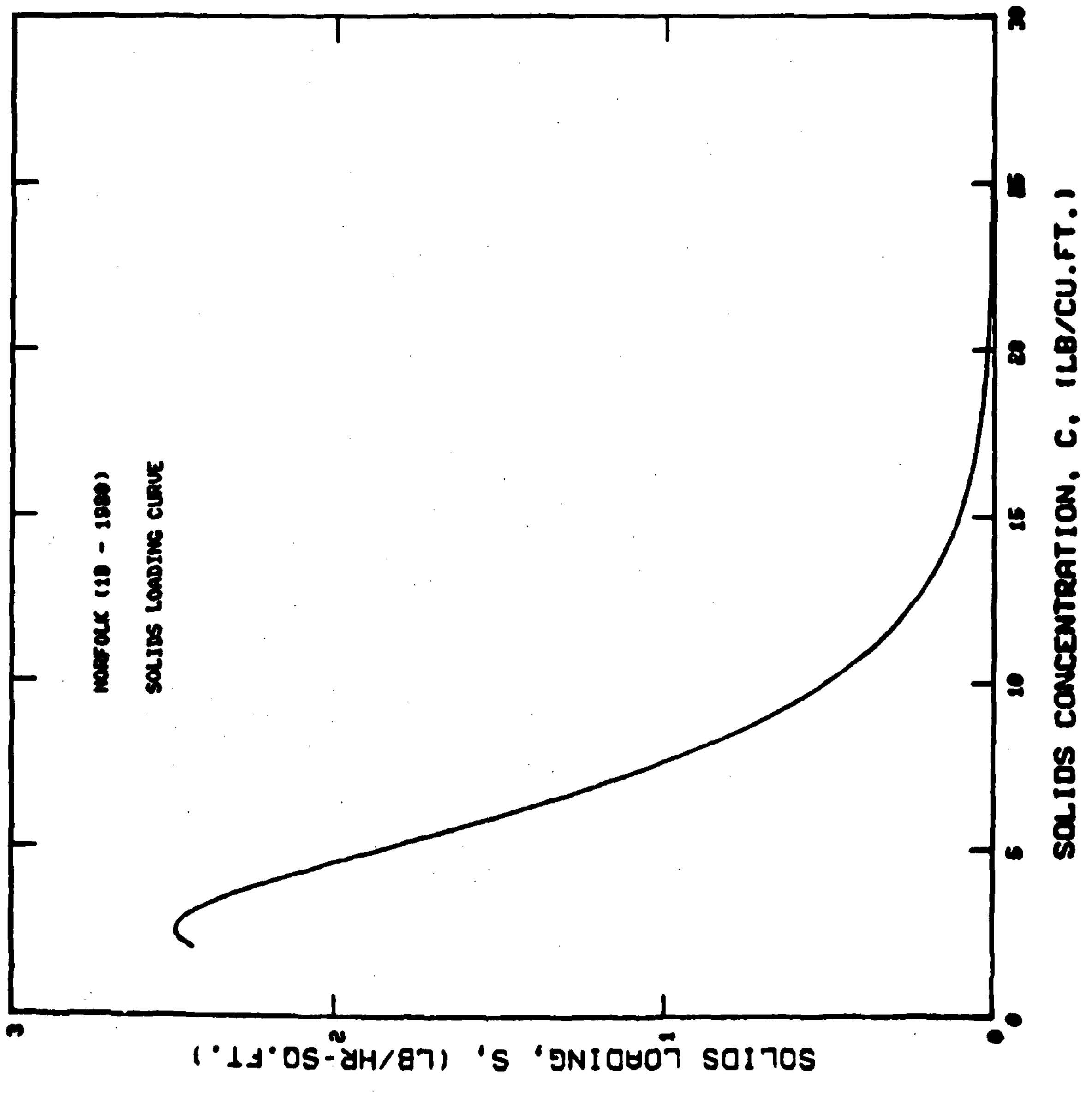
WES TR D-88-2 APPENDIX D: ADDAMS-GENERATED CURVES... 2 of 2

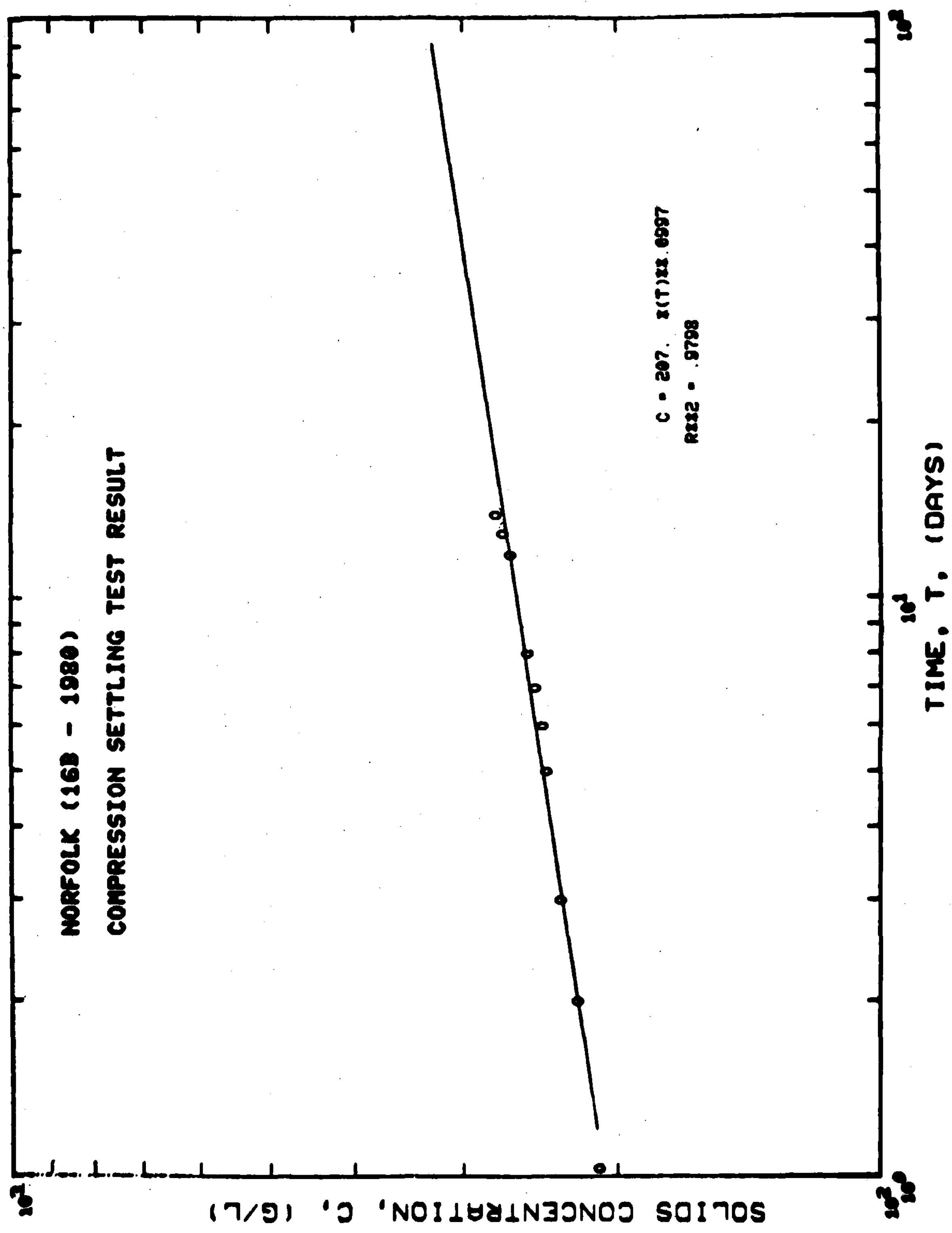
DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

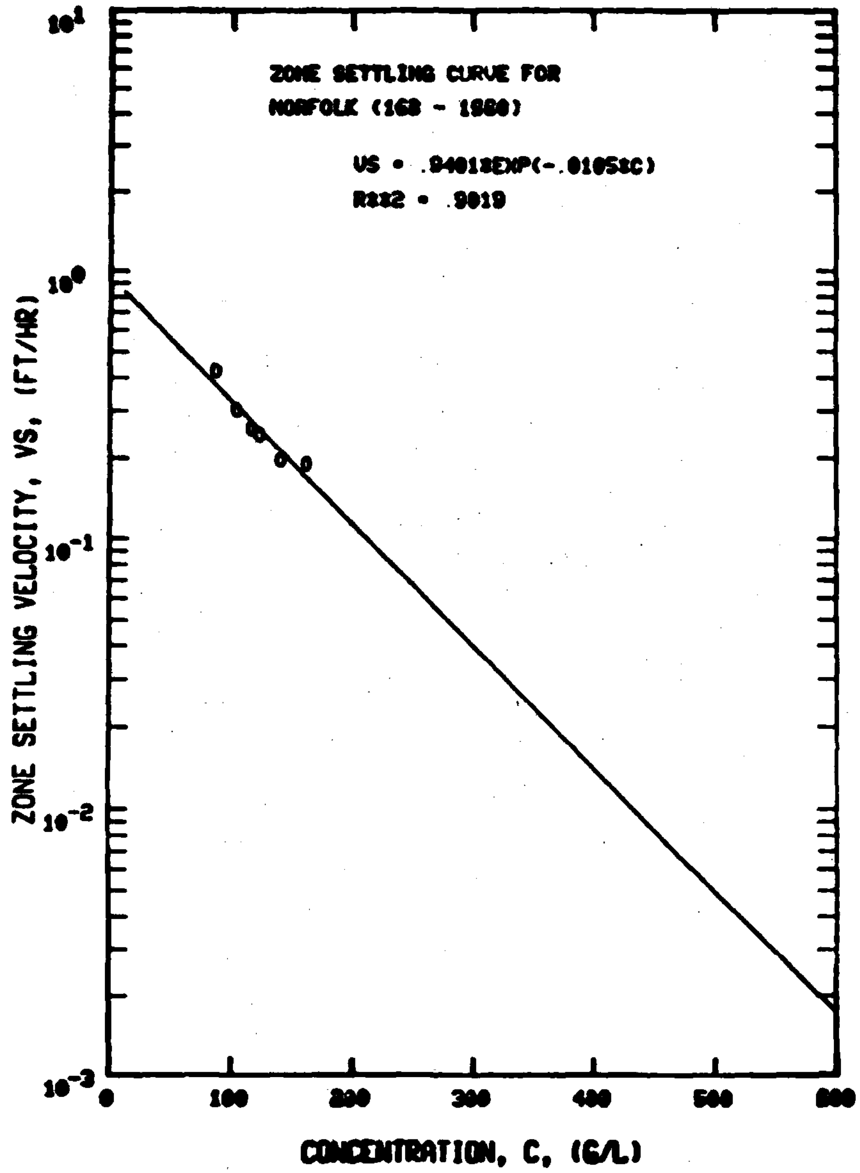
TECHNICAL REPORT D-88-2

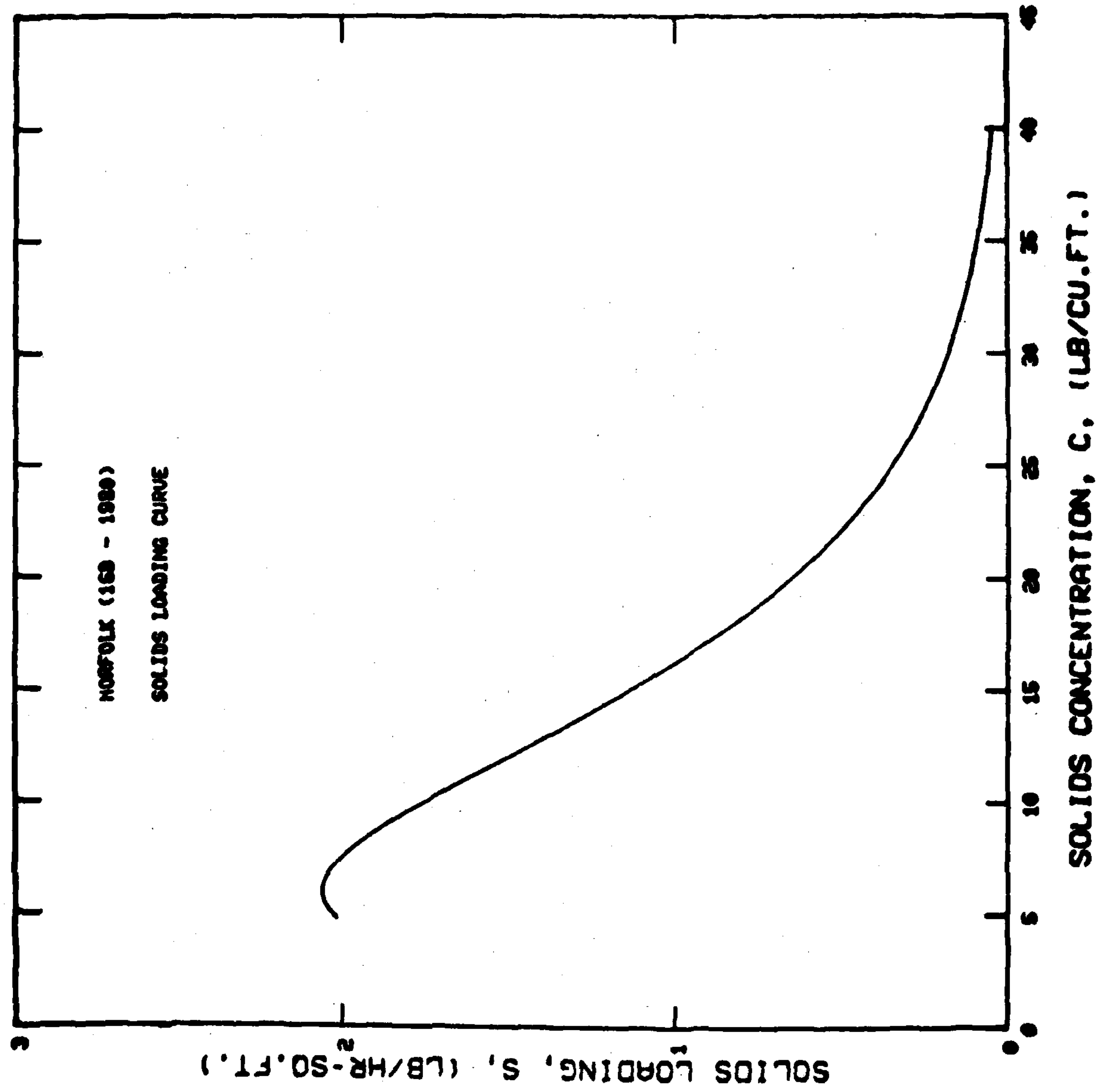
VERIFICATION OF PROCEDURES FOR DESIGNING DREDGED MATERIAL CONTAINMENT AREAS FOR SOLIDS RETENTION

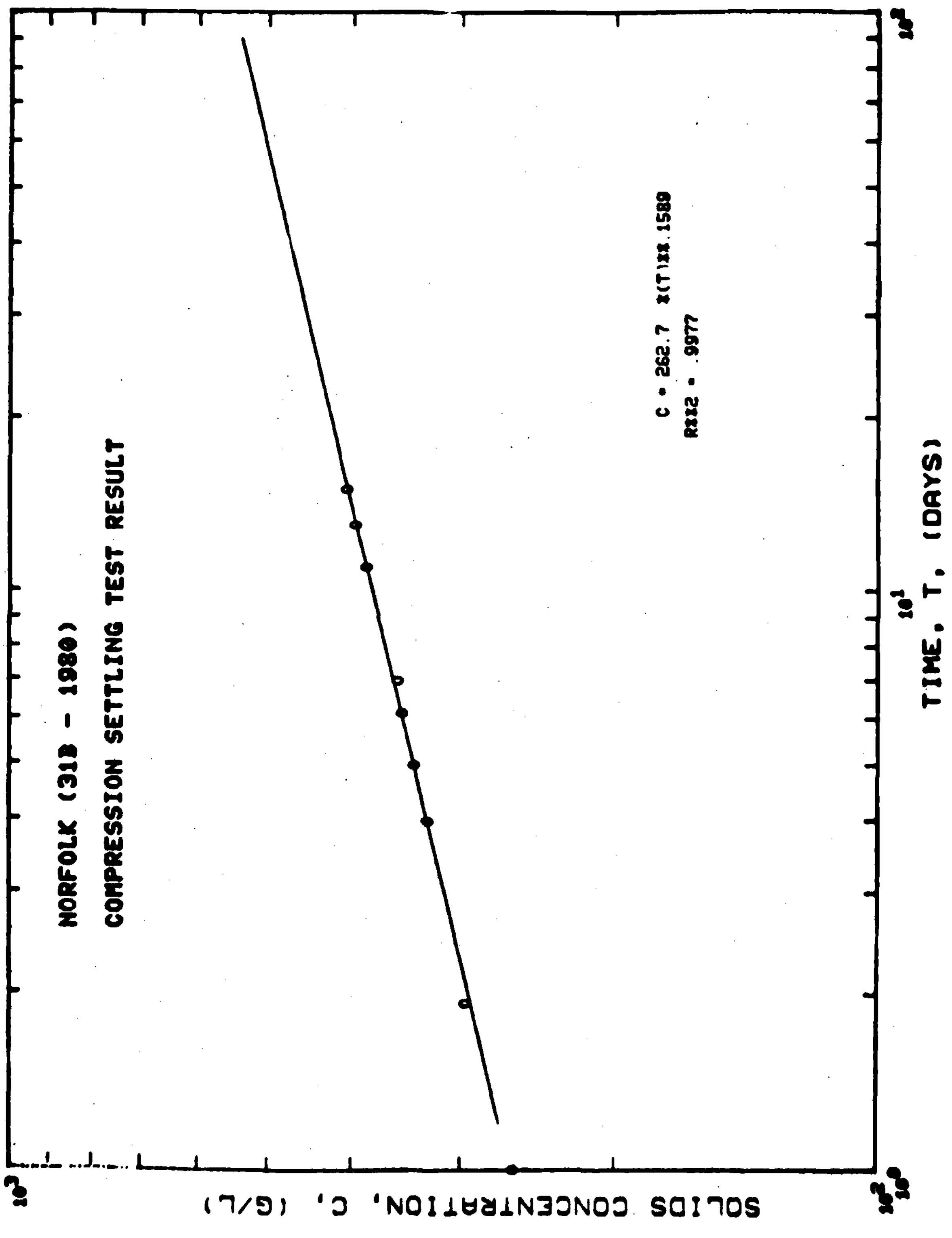
APPENDIX D: ADDAMS-GENERATED CURVES FOR COLUMN SETTLING TESTS

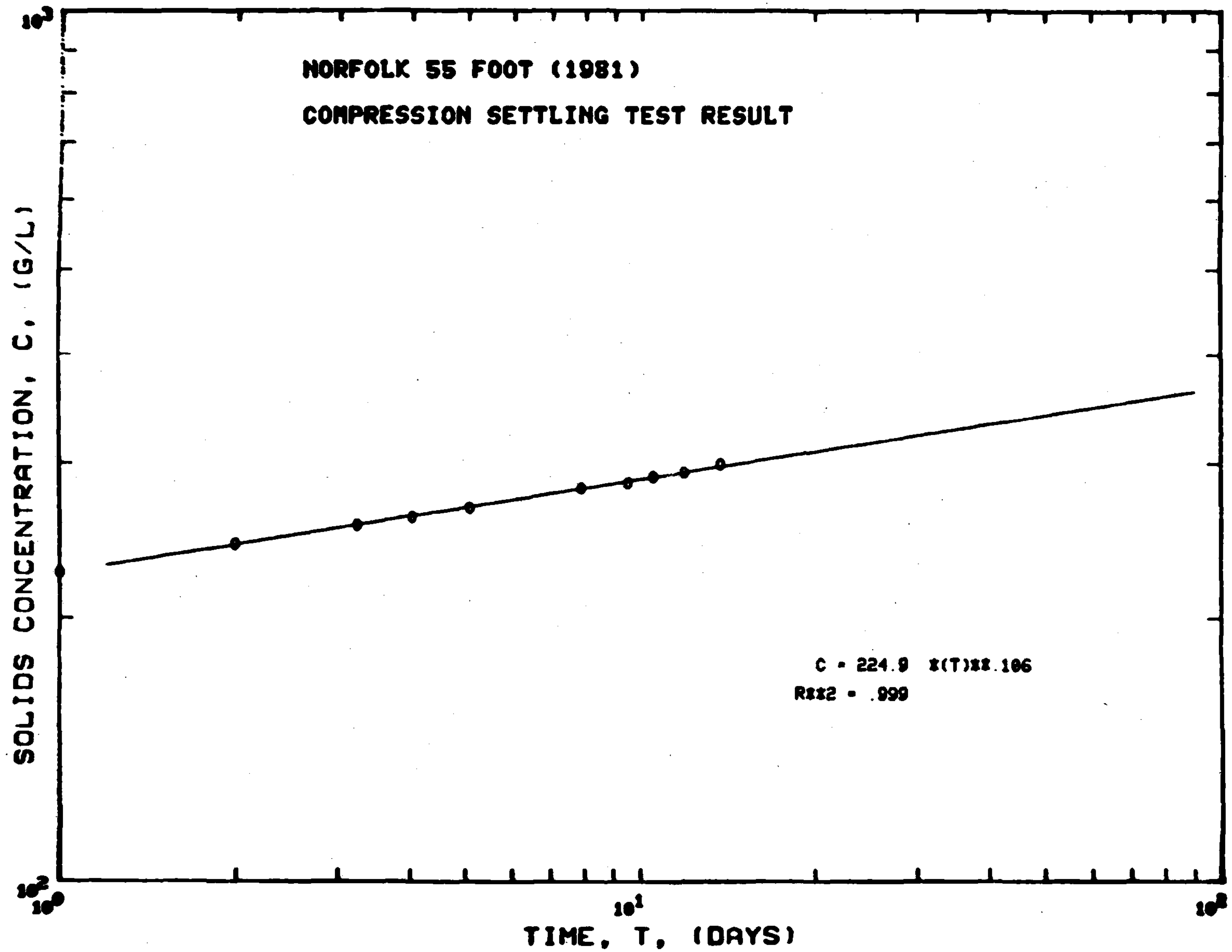

NORFOLK (1D - 1980)
SOLIDS LOADING CURVE
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
SOLIDS CONCENTRATION, C. (LB/CU.FT.)
0
1
2
3
5
10
15
20
25
30

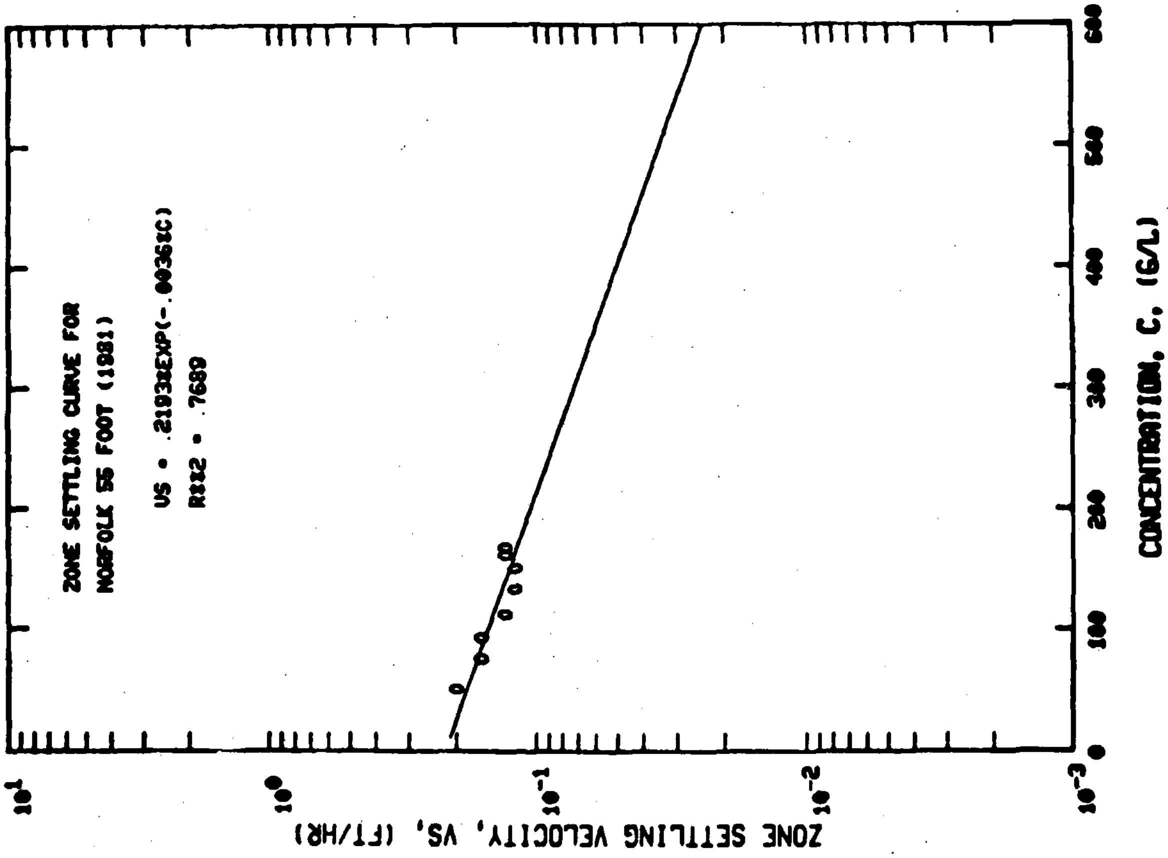

NORFOLK (16B - 1980)
COMPRESSION SETTLING TEST RESULT
C = 207. *(T)**.0997
R**2 = .9798
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)
10^0
10^1
10^2
10^2
10^3

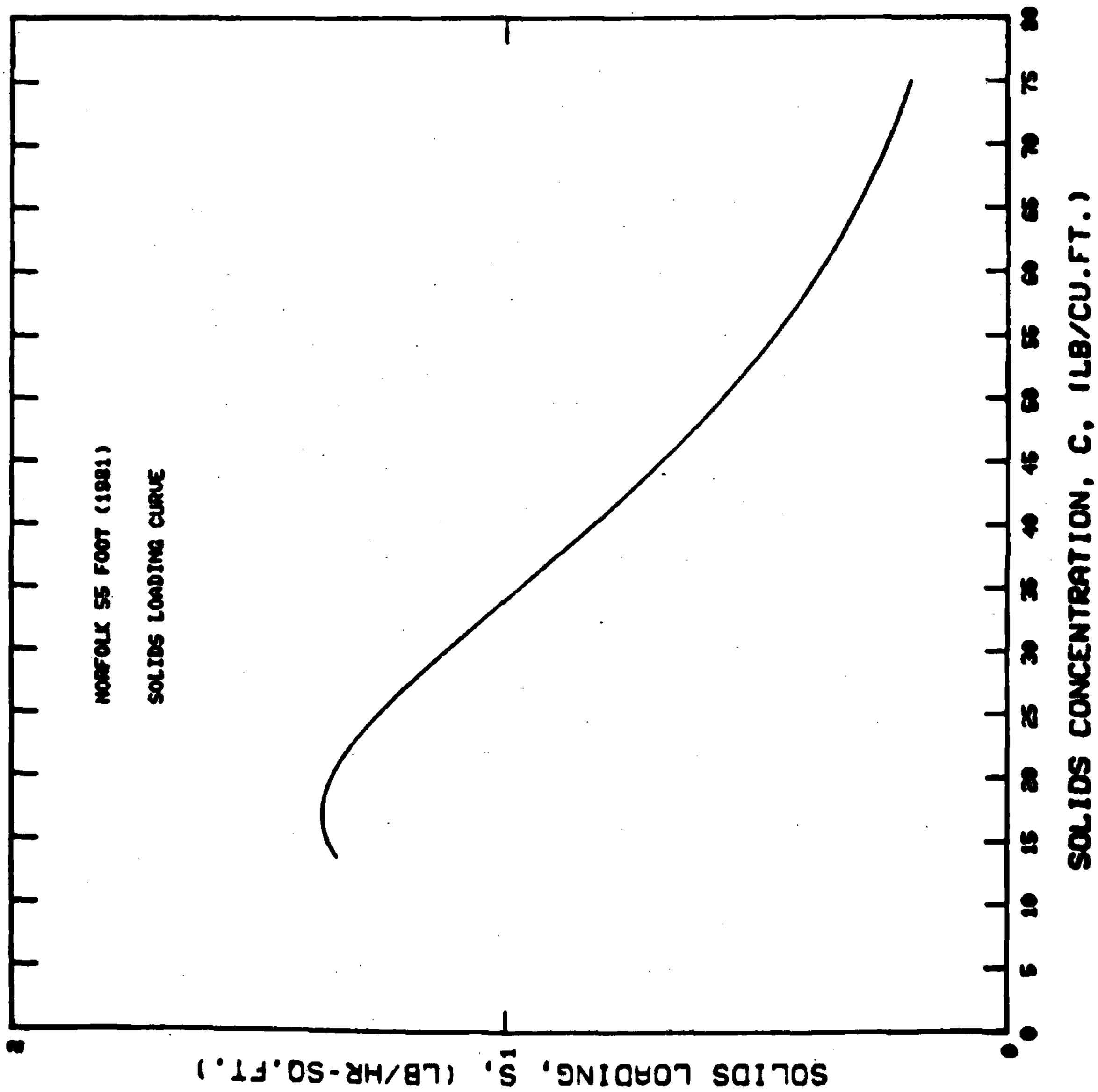

ZONE SETTLING CURVE FOR
NORFOLK (168 - 1980)
VS = .94018EXP(-.01051C)
R**2 = .9019
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

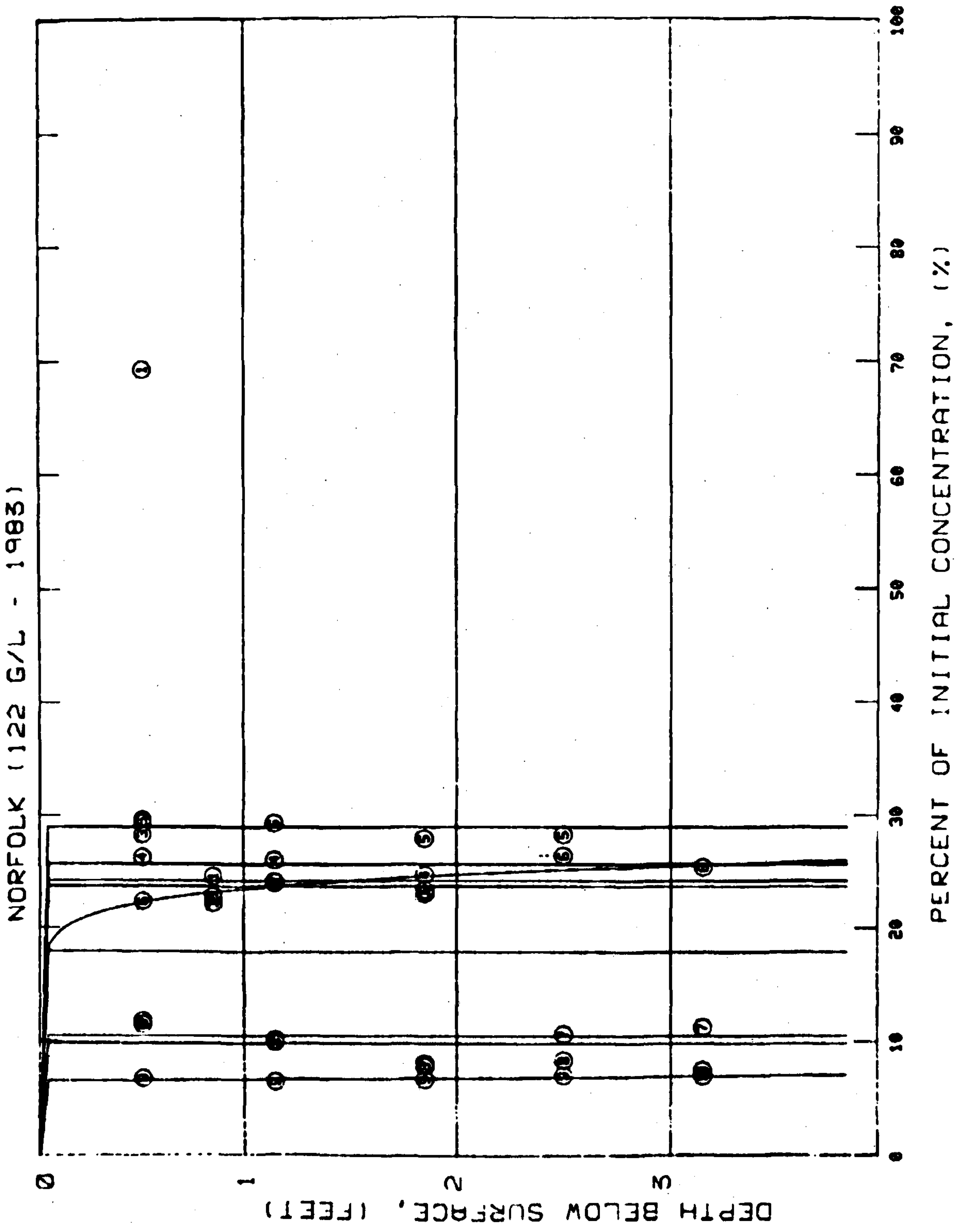

SOLIDS LOADING CURVE
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
SOLIDS CONCENTRATION, C, (LB/CU.FT.)

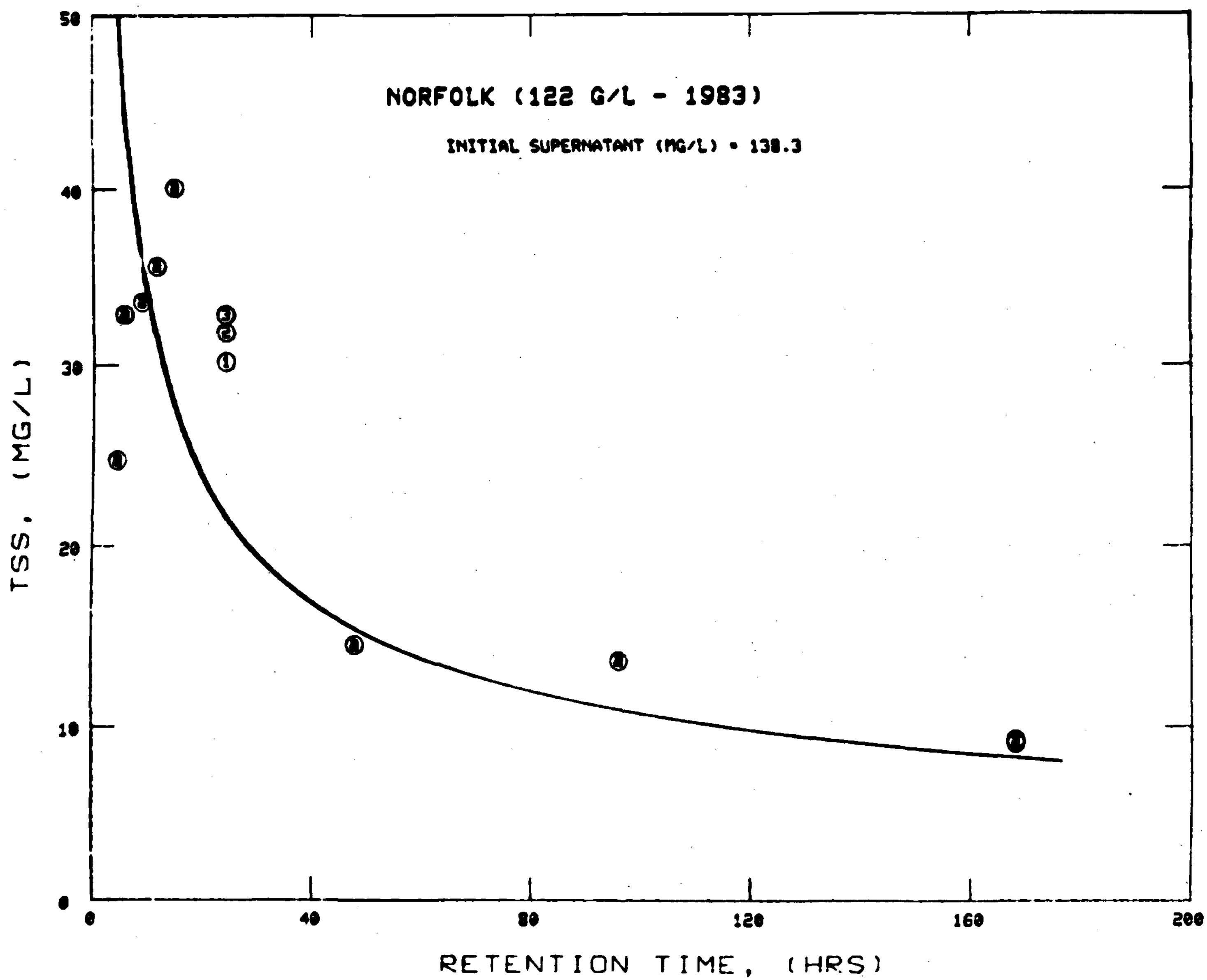

NORFOLK (31B - 1980)
COMPRESSION SETTLING TEST RESULT
C = 262.7 *(T)** .1589
R**2 = .9977
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)
10^0
10^1
10^2
10^3

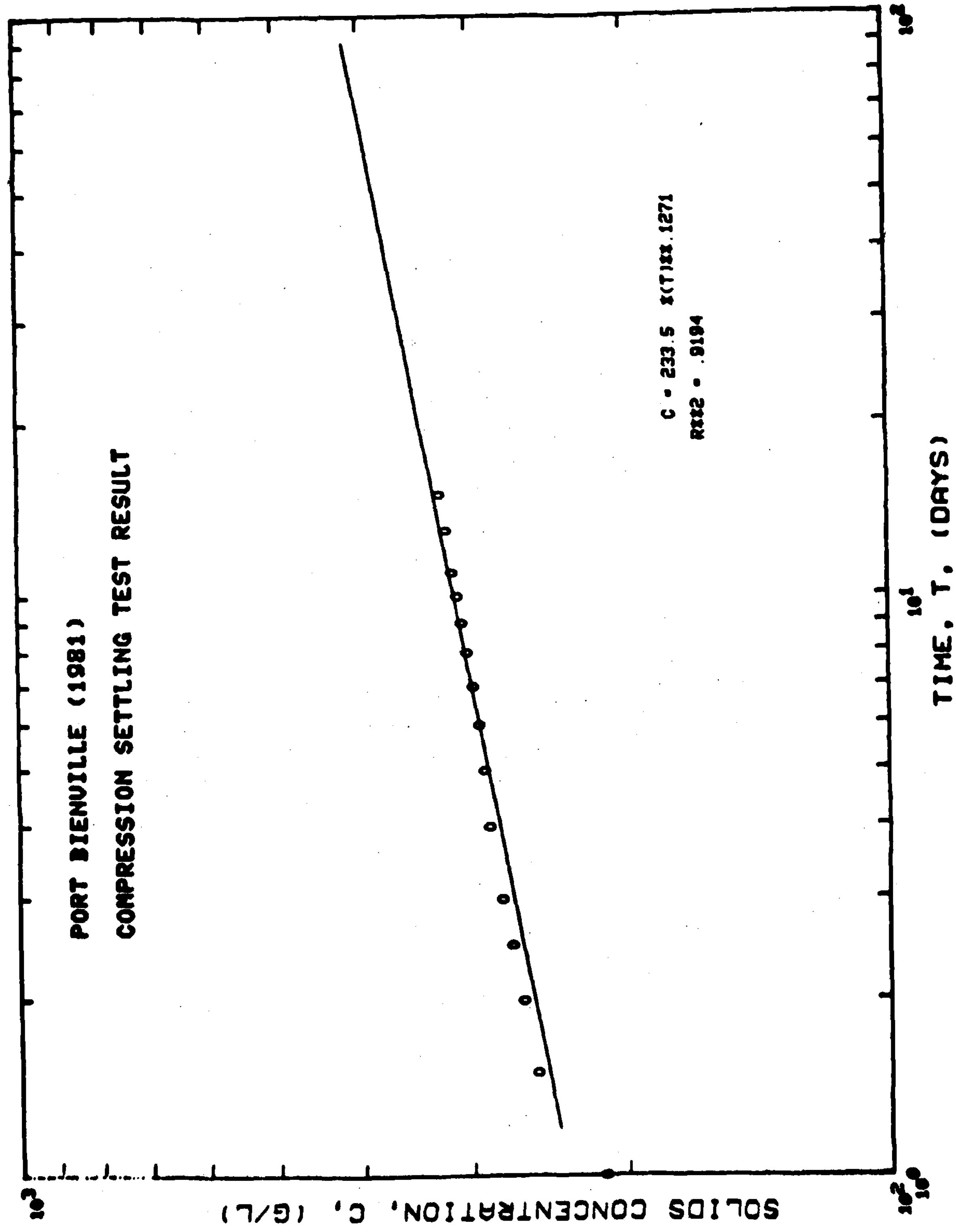

NORFOLK 55 FOOT (1981)
COMPRESSION SETTLING TEST RESULT
C = 224.9 *(T)**.106
R**2 = .999
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2

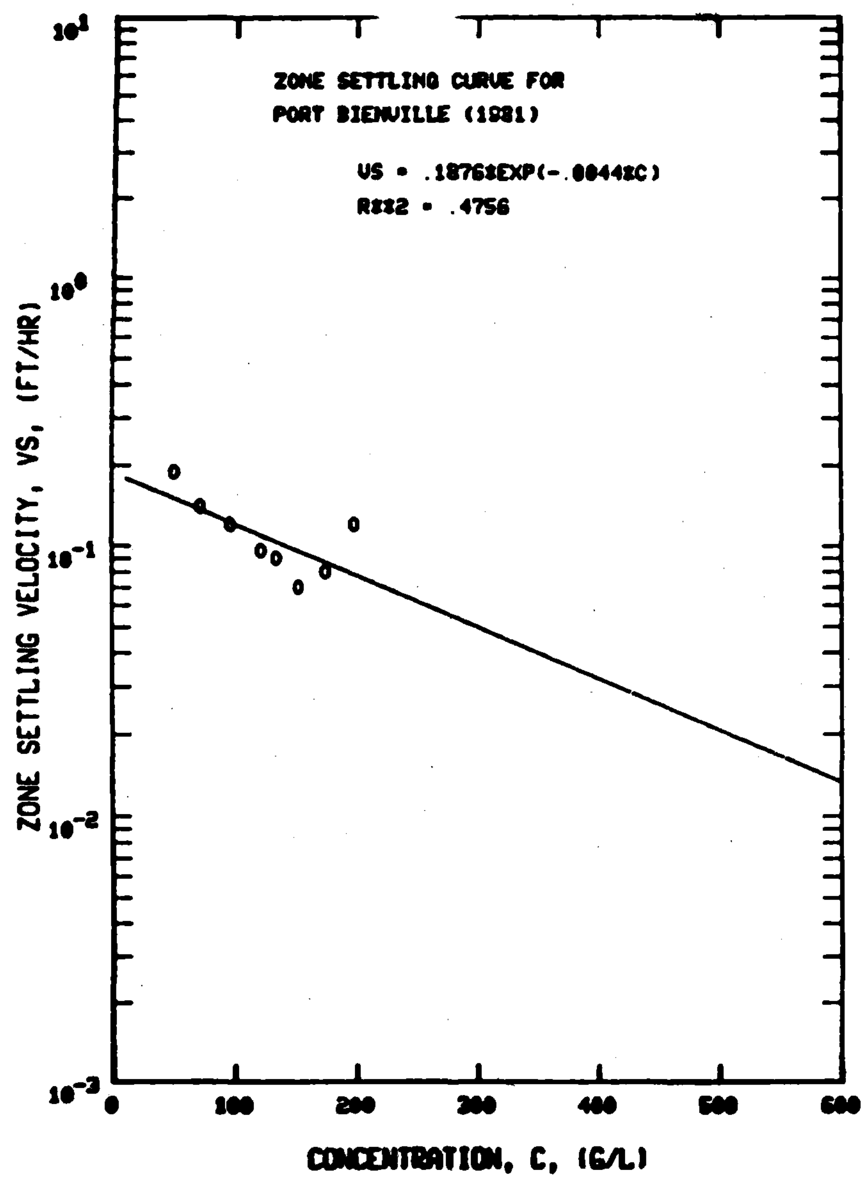

ZONE SETTLING CURVE FOR
NORFOLK 55 FOOT (1981)
VS = .2193*EXP(-.0036*C)
R**2 = .7689
CONCENTRATION, C, (G/L)
ZONE SETTLING VELOCITY, VS, (FT/HR)
0
100
200
300
400
500
600

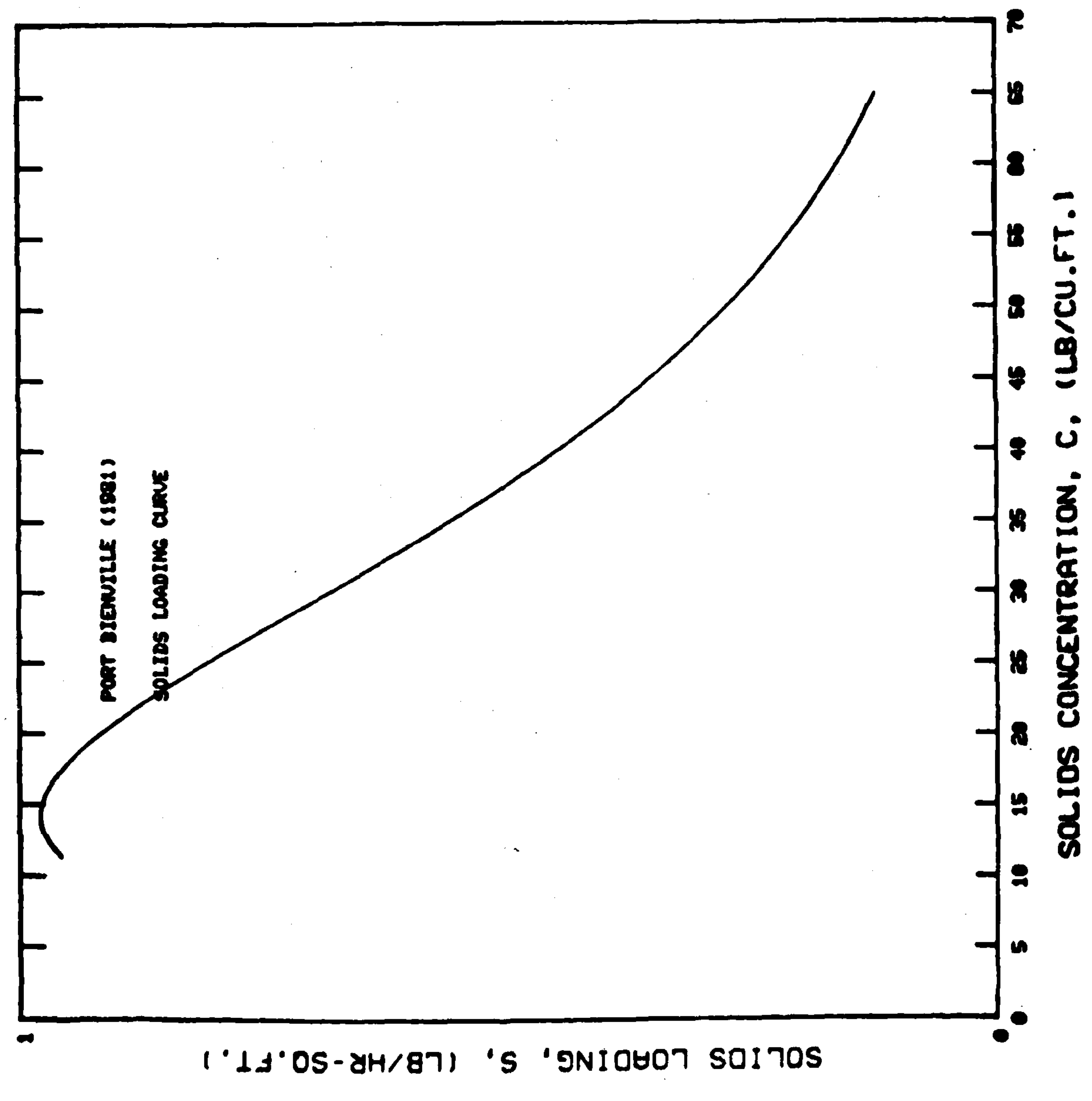

NORFOLK 55 FOOT (1981)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C. (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)

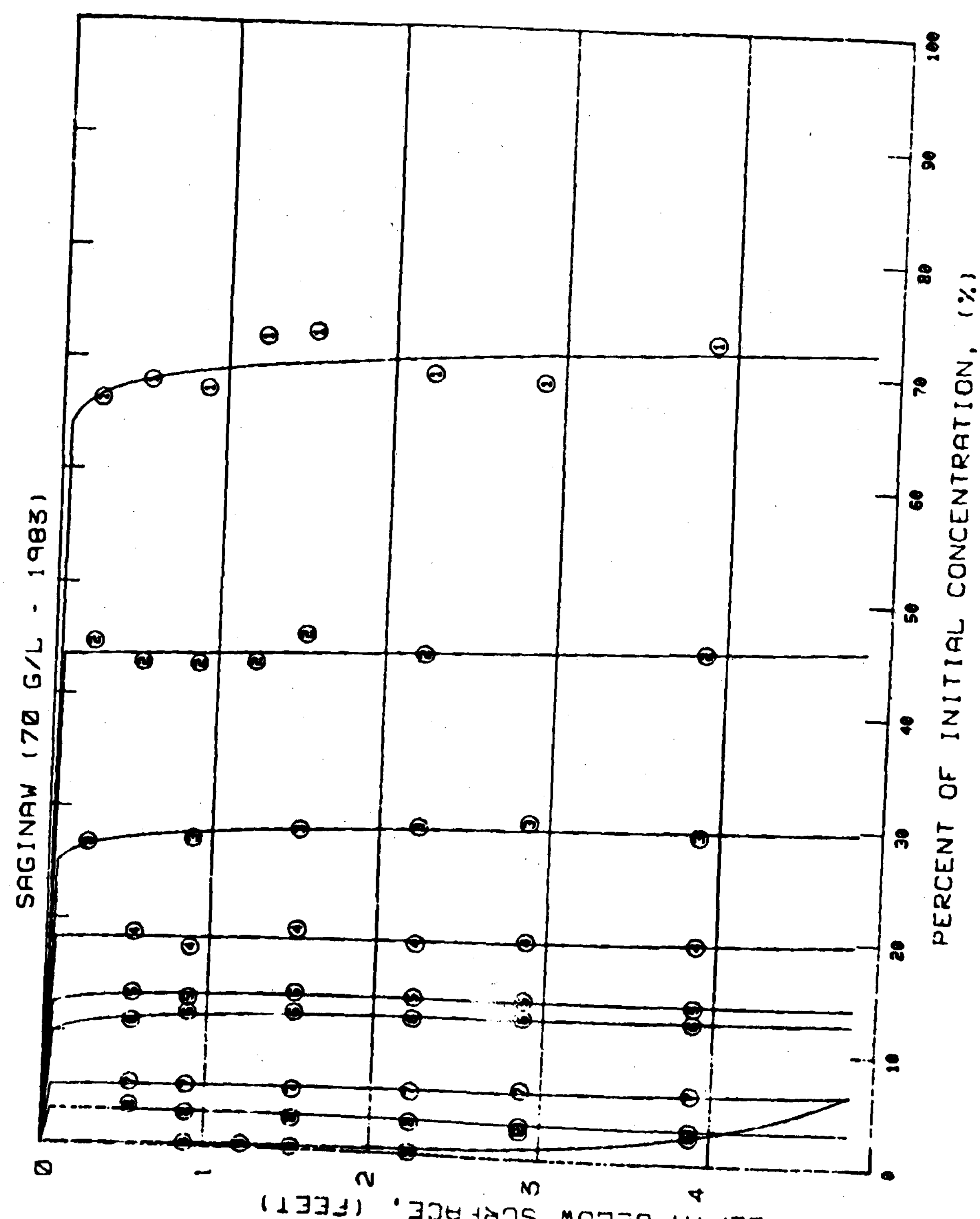

NORFOLK (122 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3

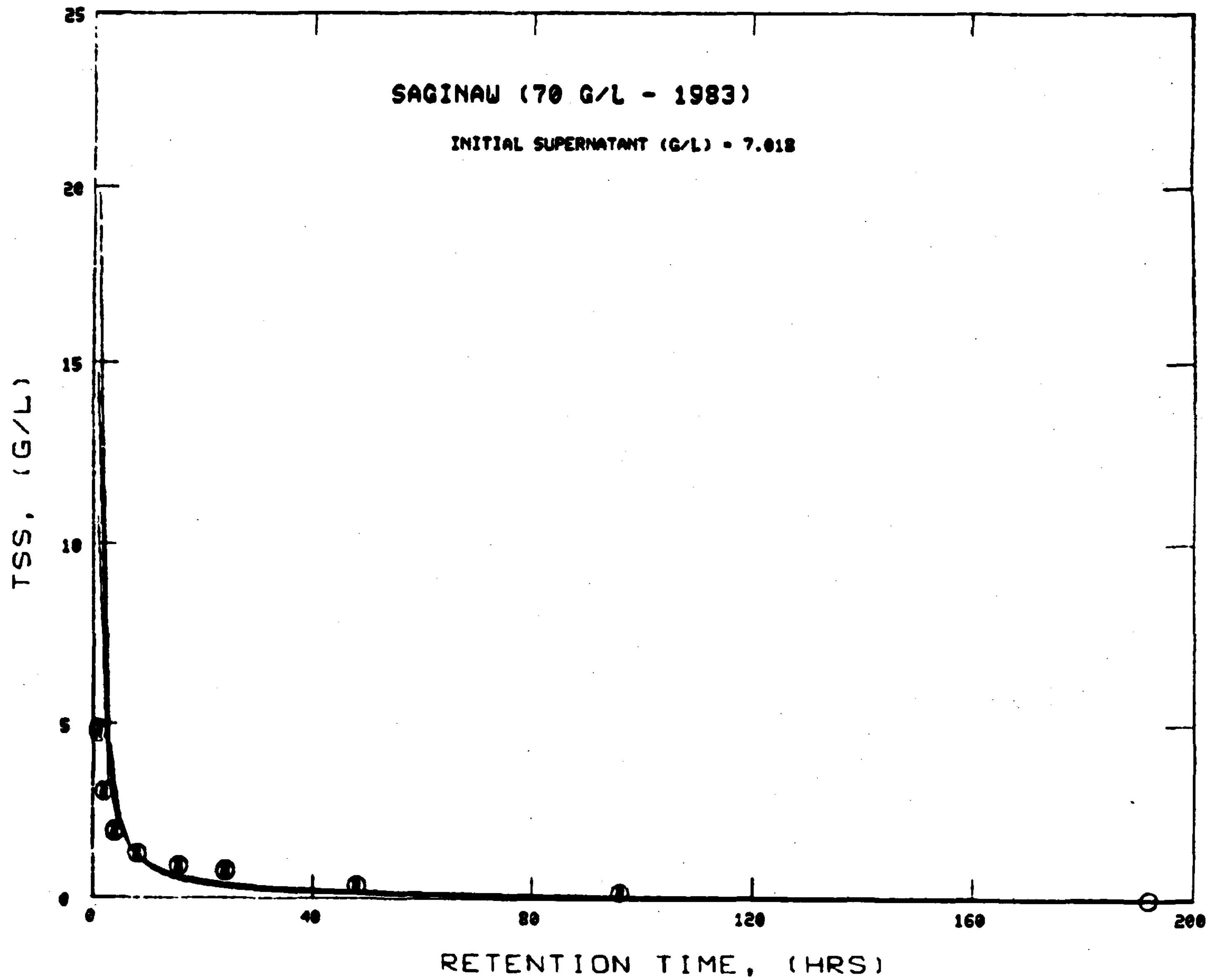

NORFOLK (122 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 138.3
TSS, (MG/L)
RETENTION TIME, (HRS)
0
40
80
120
160
200
10
20
30
40
50

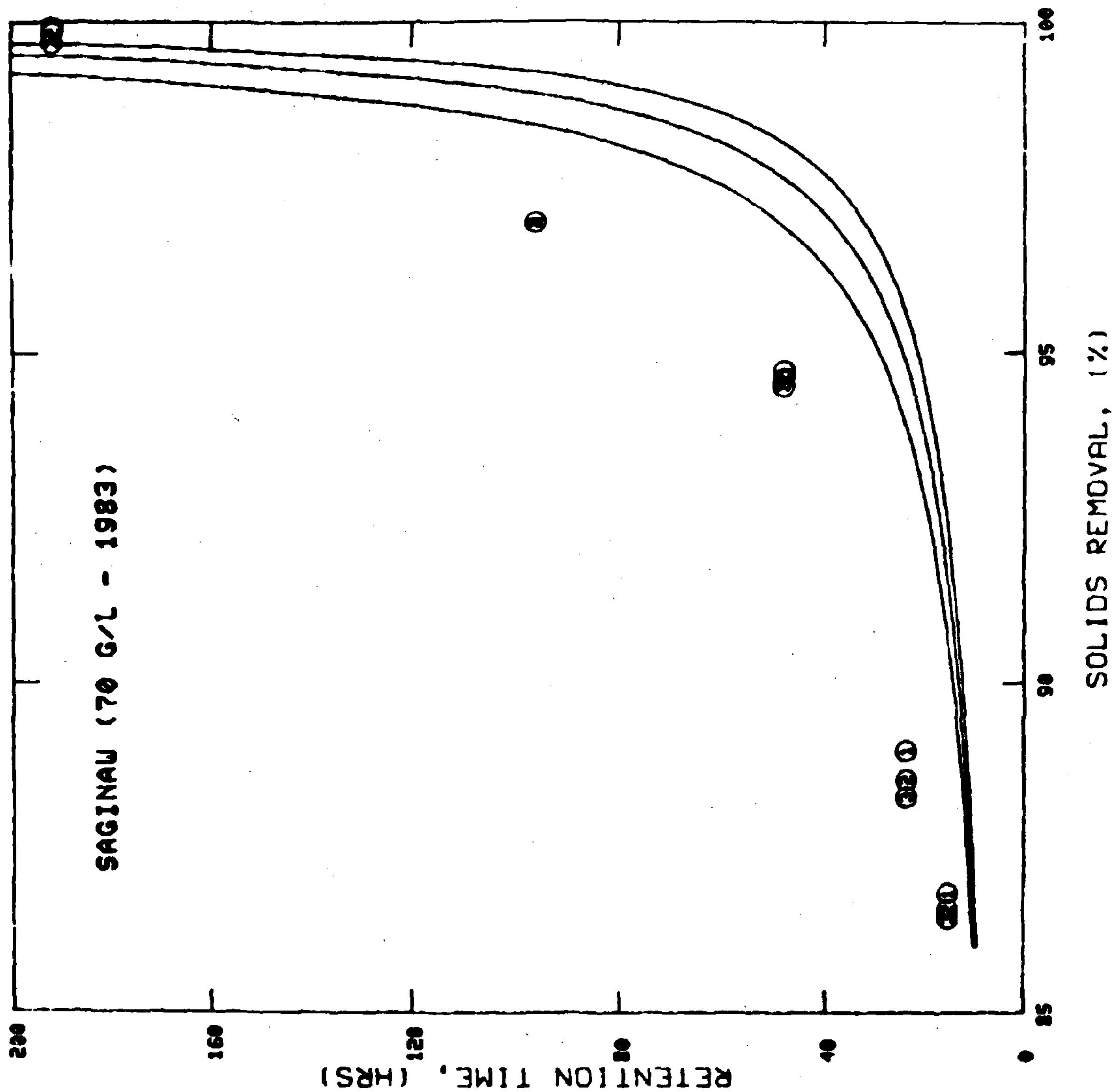

PORT BIENVILLE (1981)
COMPRESSION SETTLING TEST RESULT
C = 233.5 *(T)**.1271
R**2 = .9194
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)
10^3
10^2
10^0
10^1
10^2

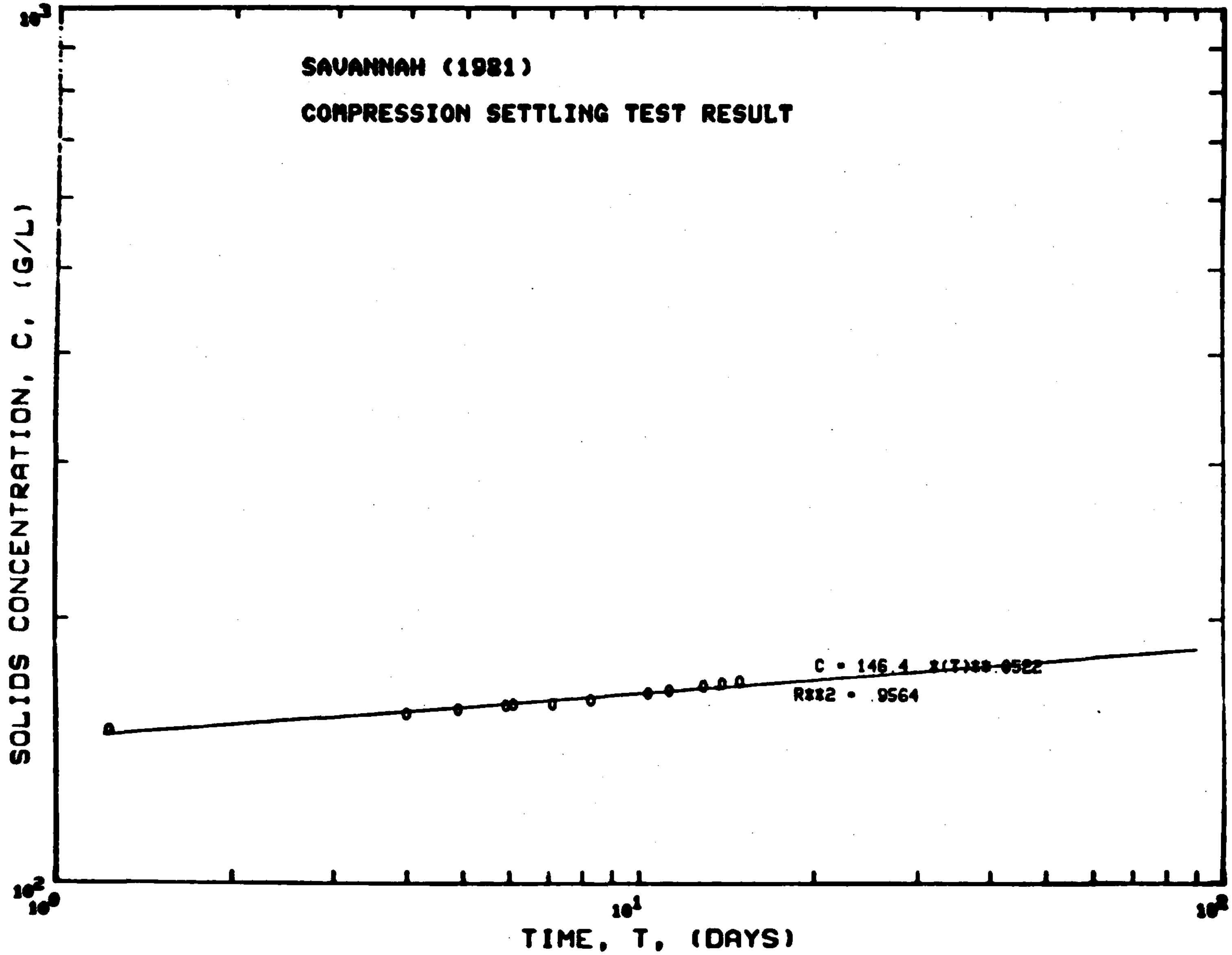

ZONE SETTLING CURVE FOR
PORT BIENVILLE (1981)
VS = .1876*EXP(-.0044*C)
R**2 = .4756
ZONE SETTLING VELOCITY, VS, (FT/HR)
CONCENTRATION, C, (G/L)
10^1
10^0
10^-1
10^-2
10^-3
0
100
200
300
400
500
600

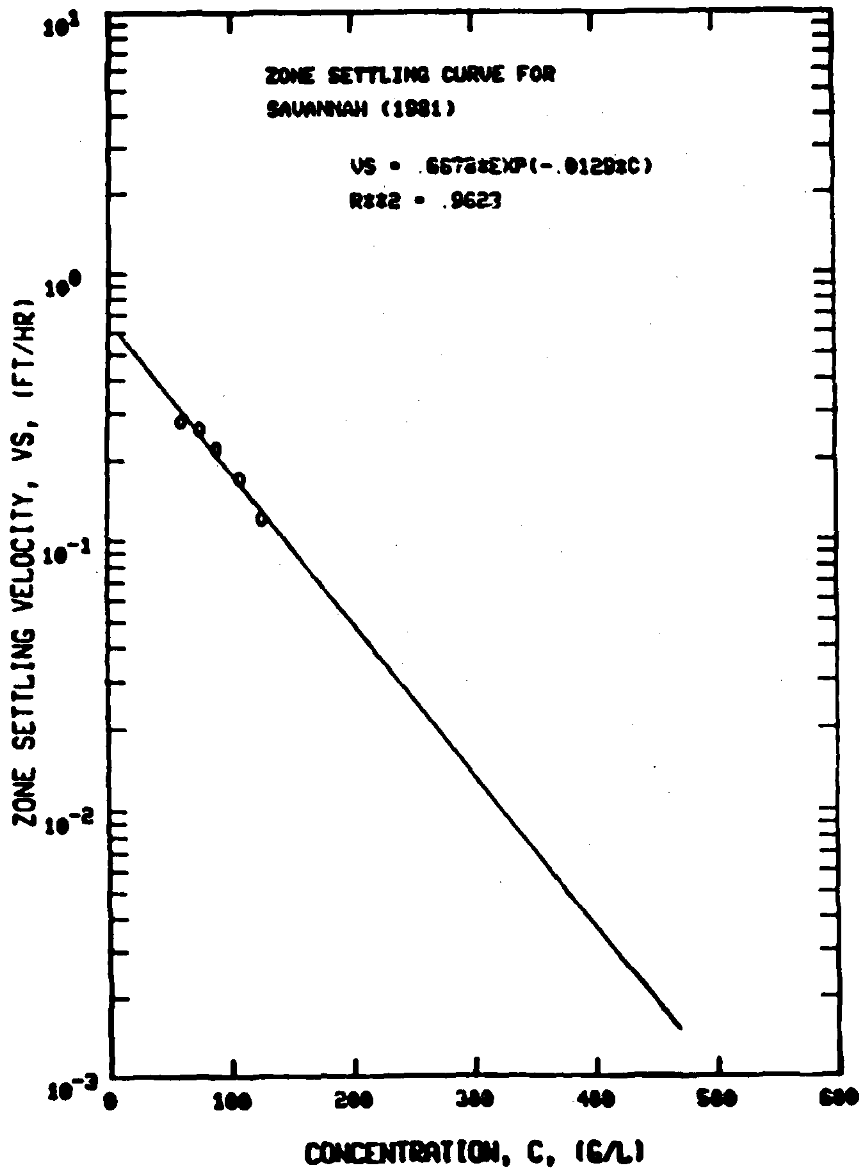

PORT BIENVILLE (1981)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
1

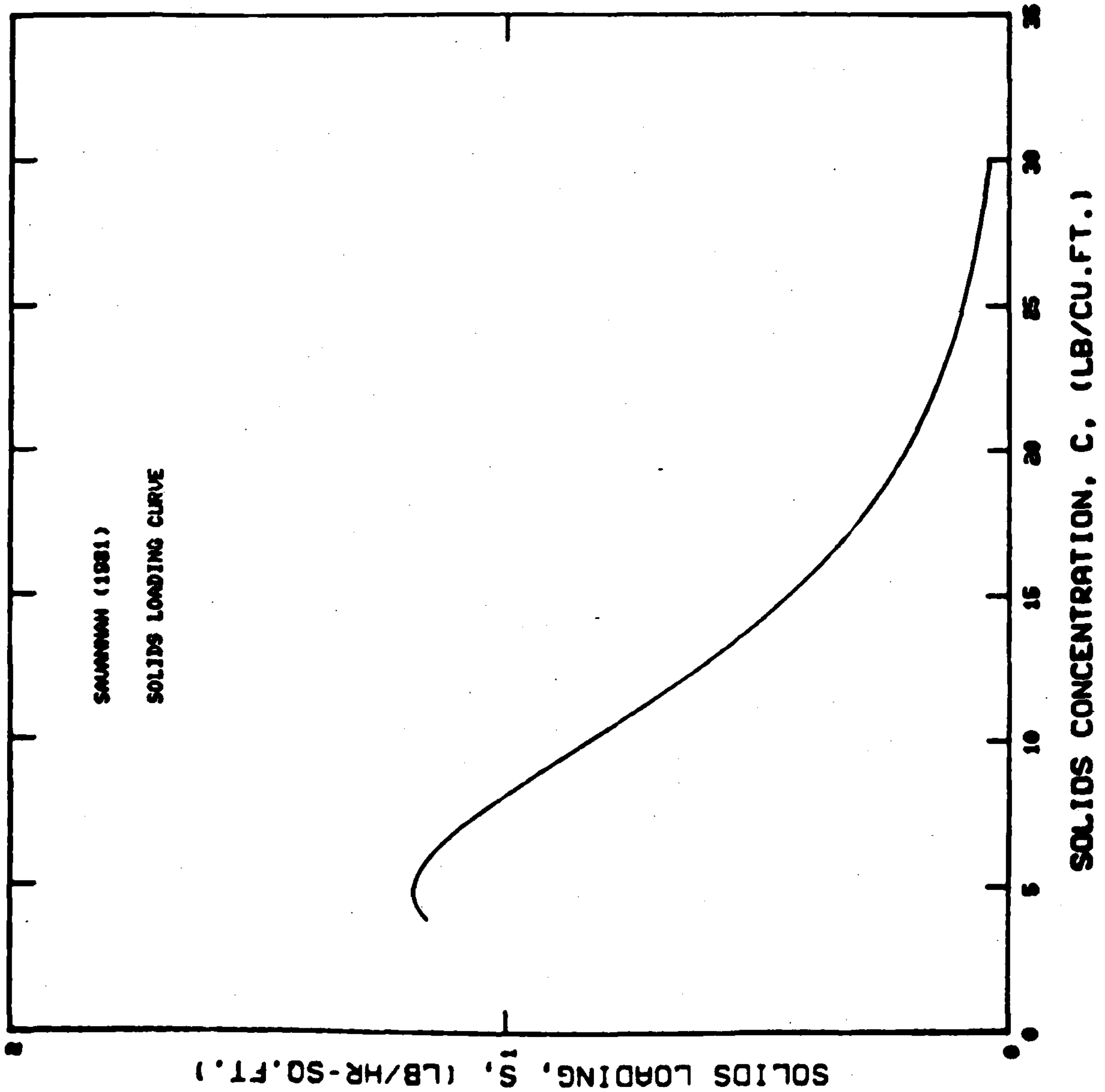

SAGINAW (70 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4


SAGINAW (70 G/L - 1983)
INITIAL SUPERNATANT (G/L) = 7.018
TSS, (G/L)
RETENTION TIME, (HRS)
0
5
10
15
20
25
0
40
80
120
160
200

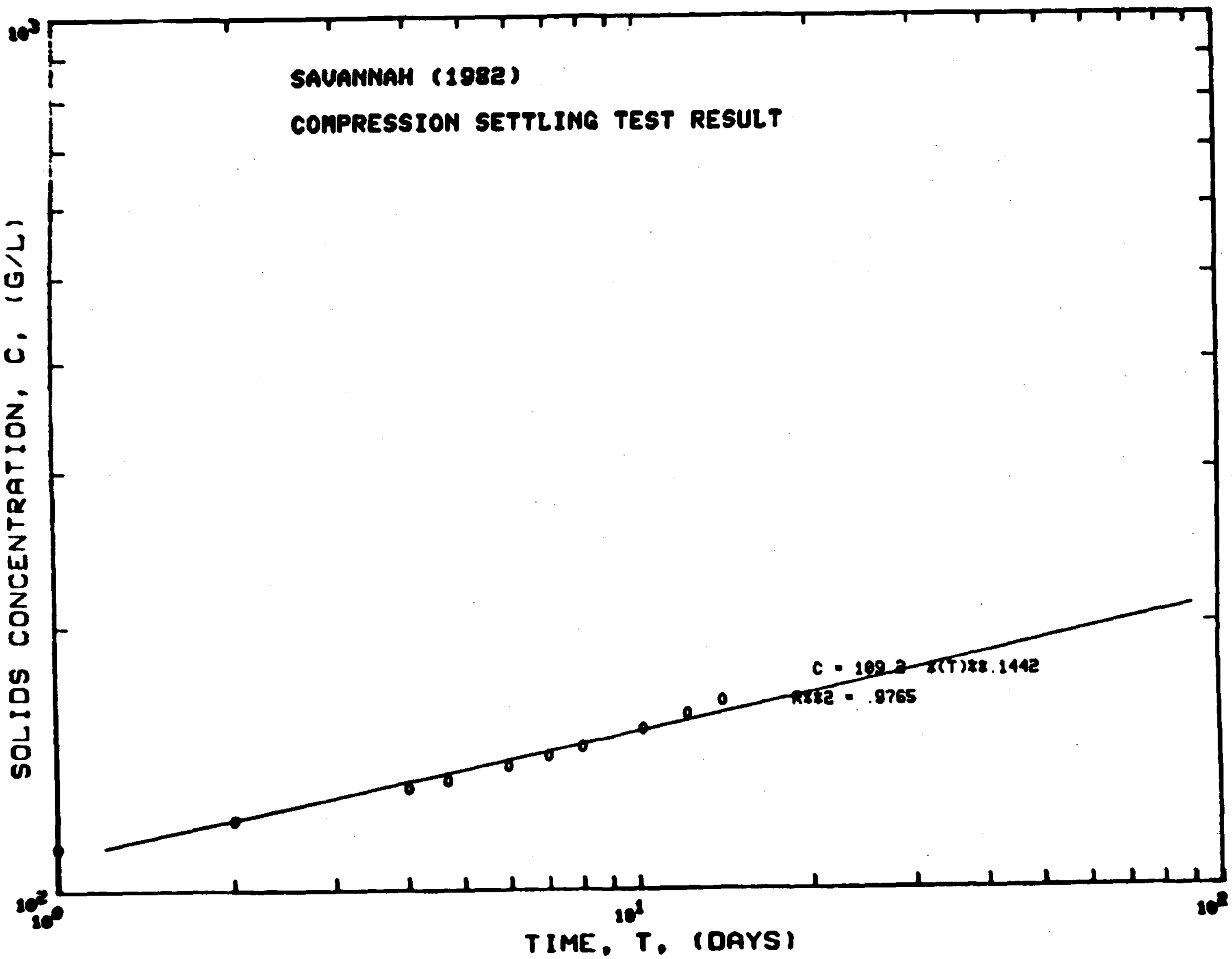

SAGINAW (70 G/L - 1983)
RETENTION TIME, (HRS)
SOLIDS REMOVAL, (%)
200
160
120
80
40
0
85
90
95
100

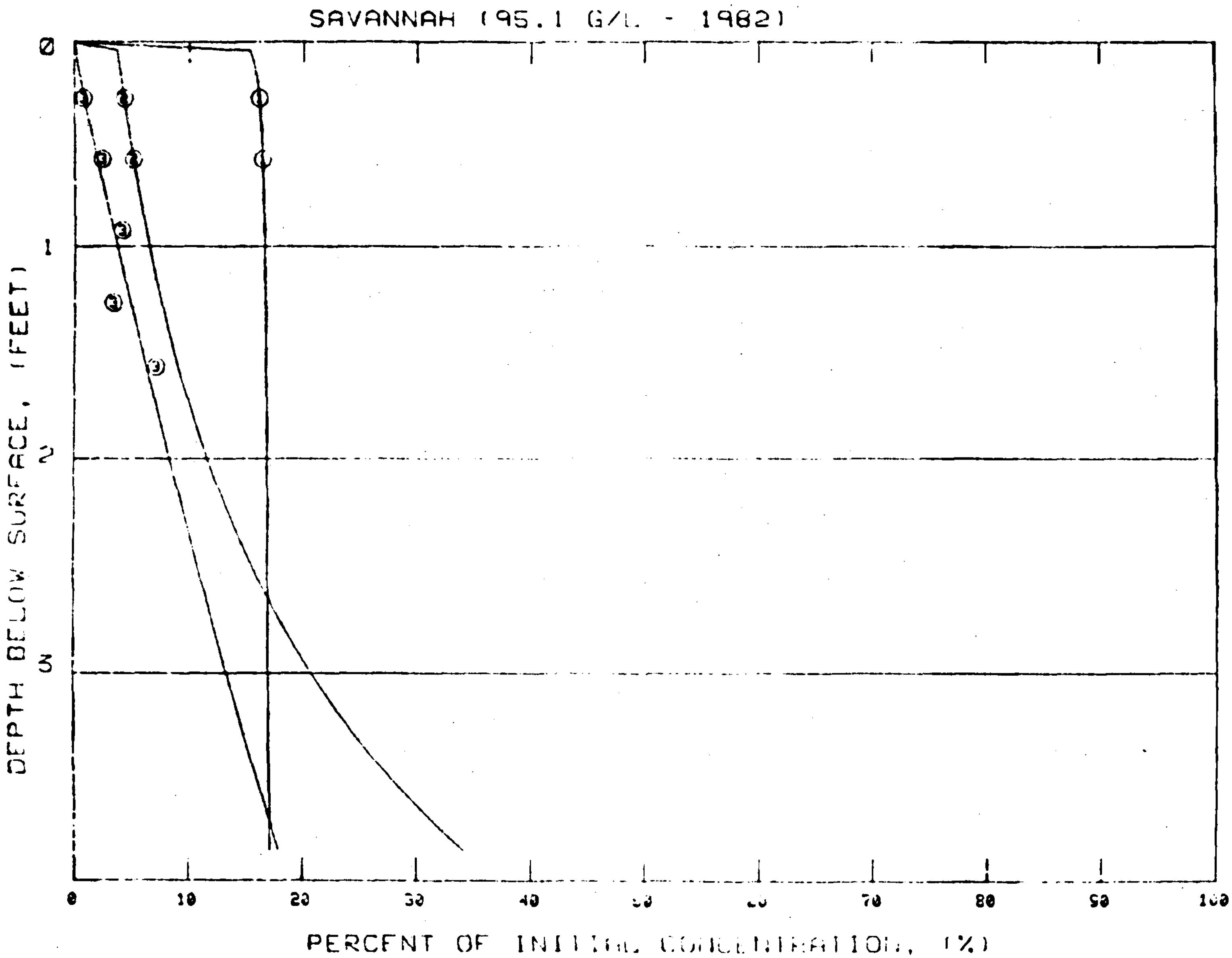

SAVANNAH (1981)
COMPRESSION SETTLING TEST RESULT
C = 146.4 X(T)**.0522
R**2 = .9564
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10^3
10^2
10^0
10^1
10^2


ZONE SETTLING CURVE FOR
SAVANNAH (1981)
VS = .6678*EXP(-.0129*C)
R**2 = .9623
ZONE SETTLING VELOCITY, VS, (FT/HR)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
100
200
300
400
500
600
CONCENTRATION, C, (G/L)

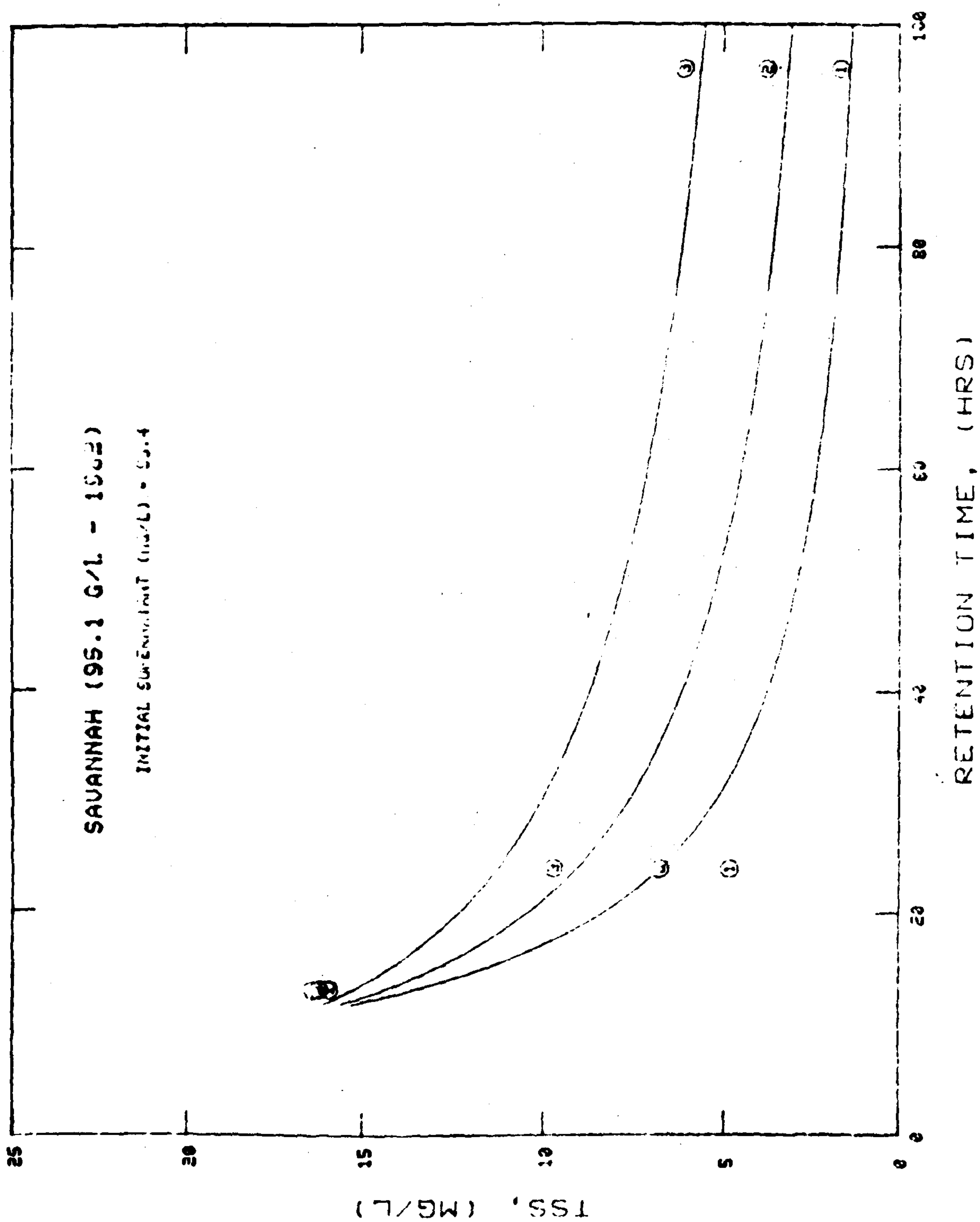


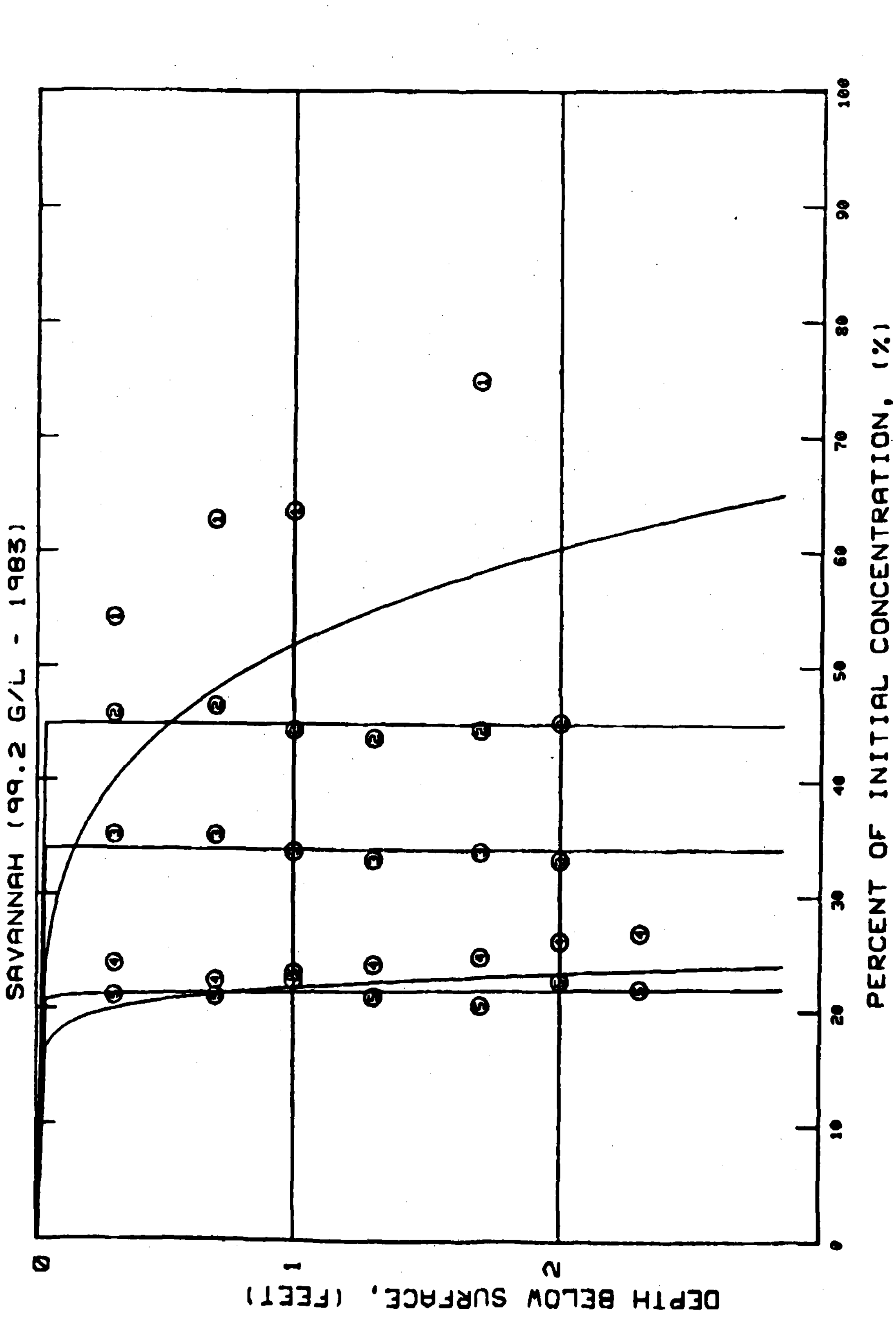
SAVANNAH (1981)
SOLIDS LOADING CURVE
SOLIDS CONCENTRATION, C, (LB/CU.FT.)
SOLIDS LOADING, S, (LB/HR-SQ.FT.)
5
10
15
20
25
30
35

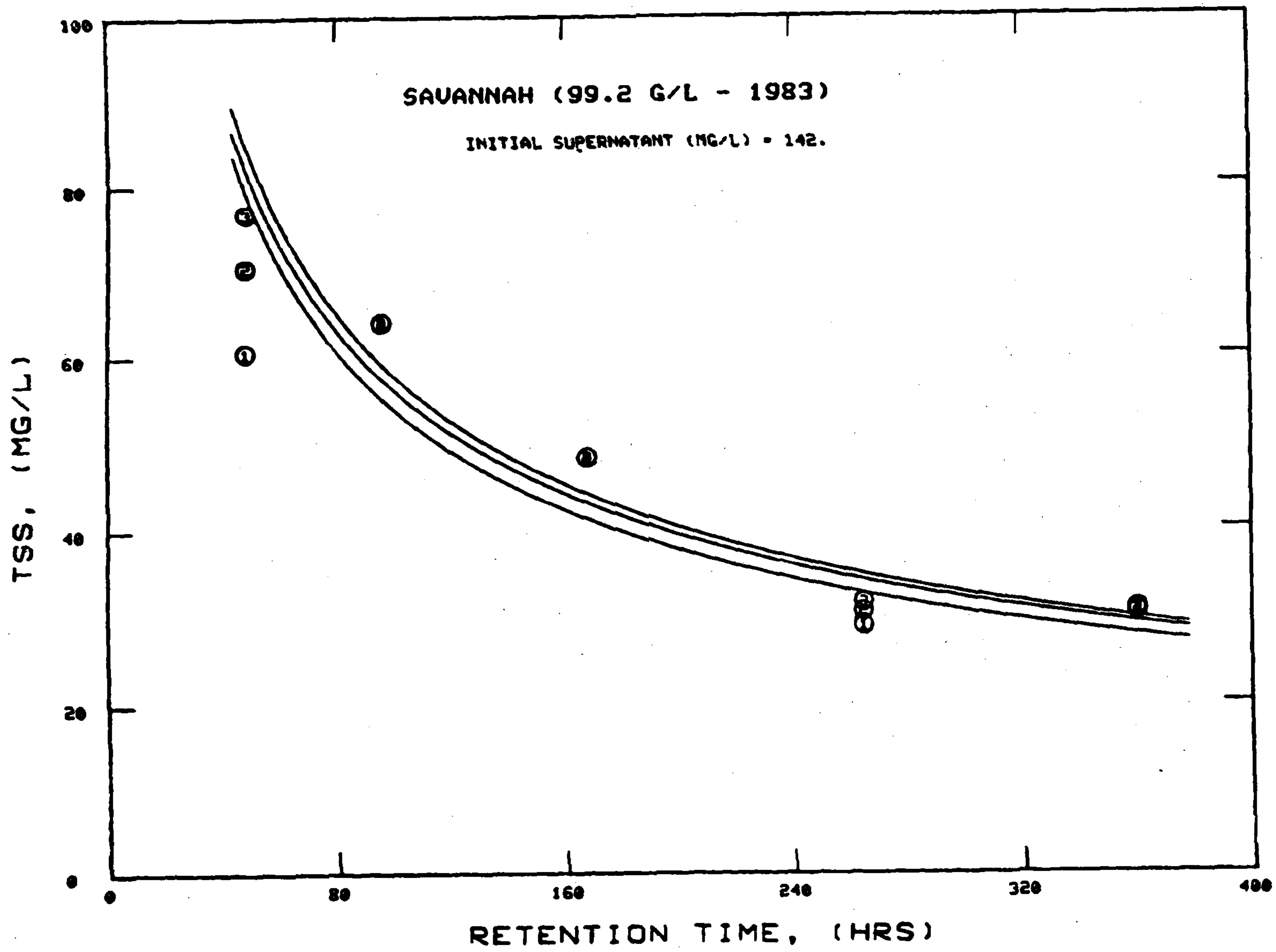

SAVANNAH (1982)
COMPRESSION SETTLING TEST RESULT
C = 109.2 *(T)**.1442
R**2 = .9765
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)
10³
10²
10⁰
10¹
10²

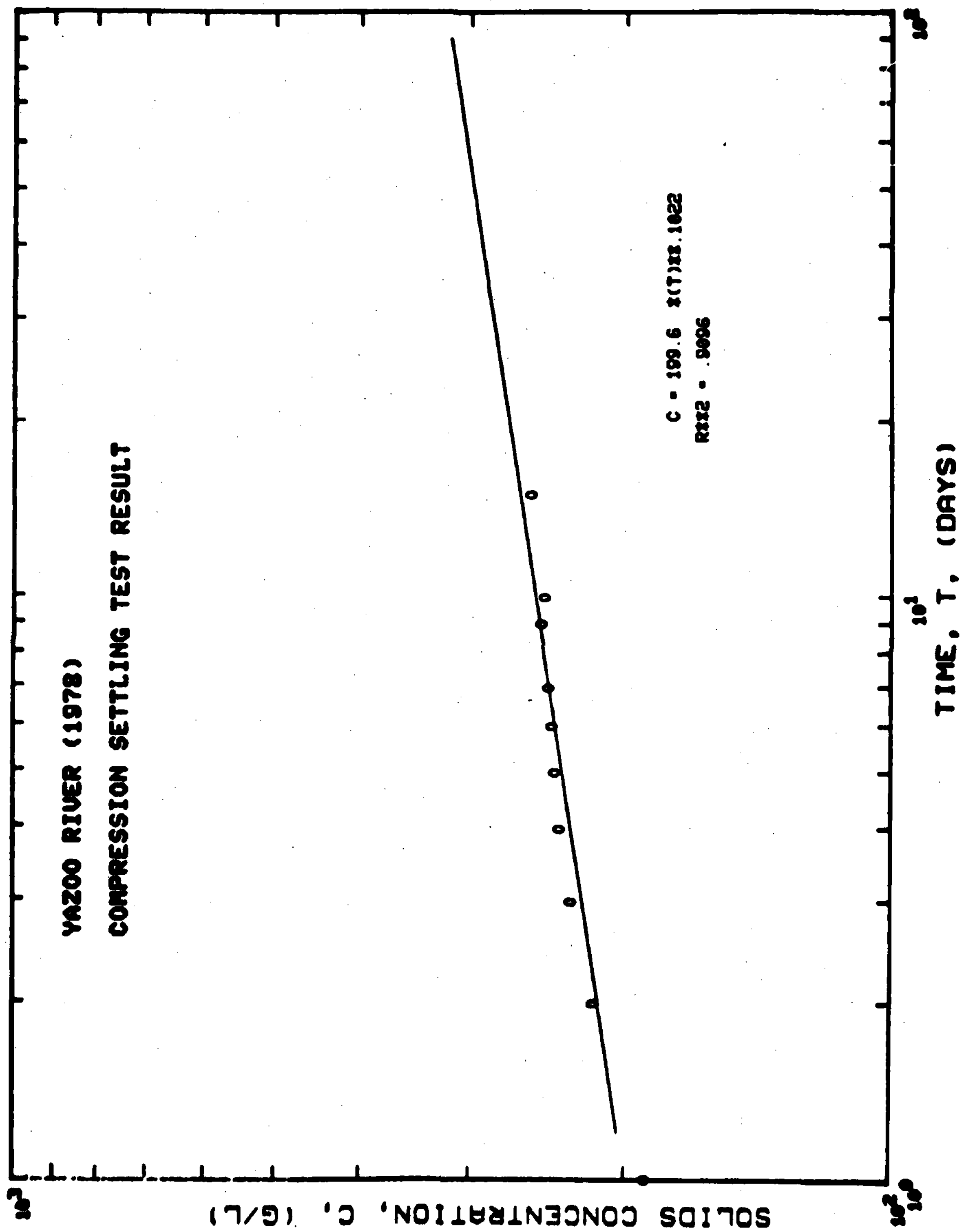


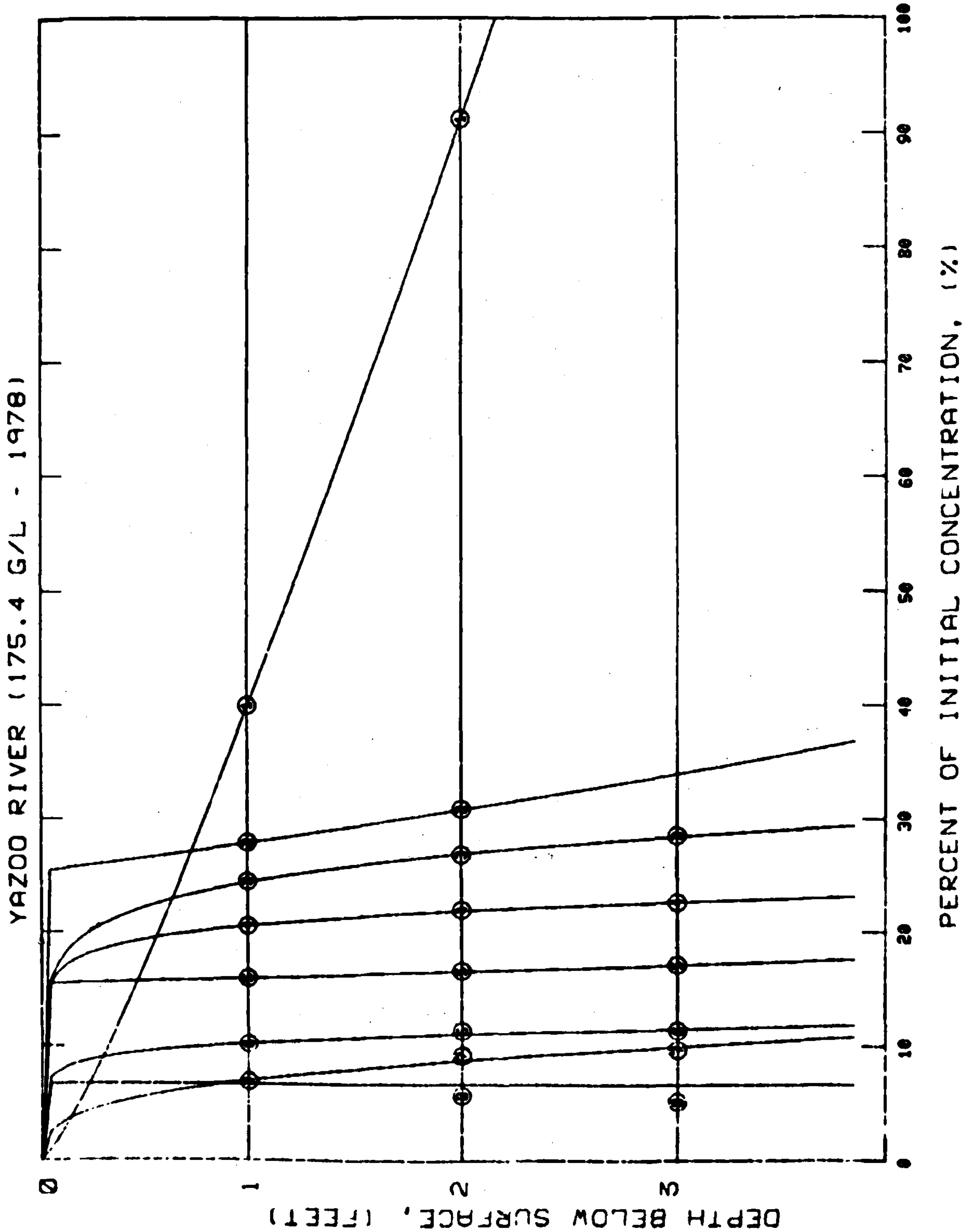
SAVANNAH (95.1 G/L - 1982)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
0
10
20
30
40
70
80
90
100
PERCENT OF INITIAL CONCENTRATION, (%)


SAVANNAH (95.1 G/L -
INITIAL
TSS, (MG/L)
0
5
10
15
20
25
RETENTION TIME, (HRS)
0
20
40
60
80
100

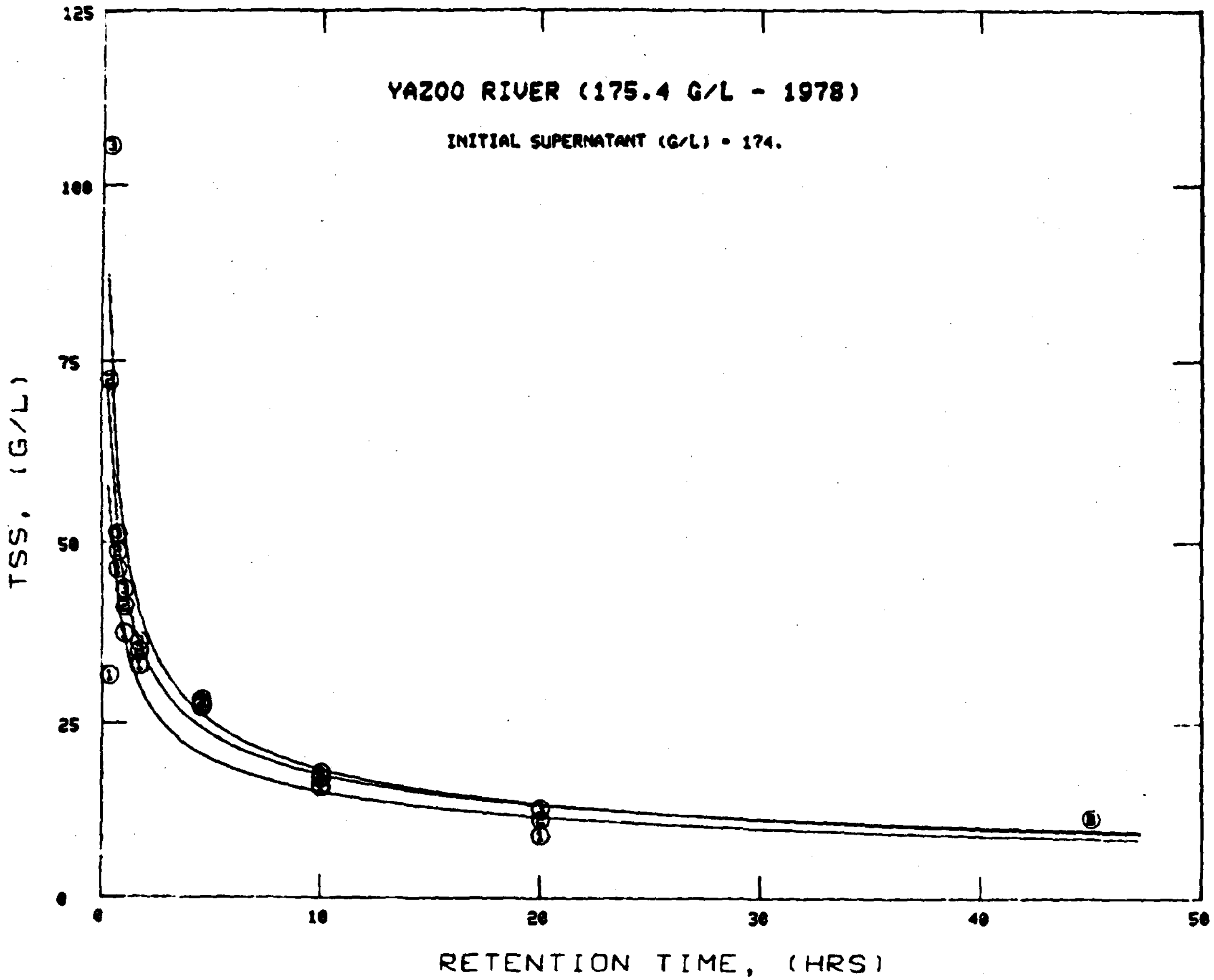

SAVANNAH (99.2 G/L - 1983)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2


SAVANNAH (99.2 G/L - 1983)
INITIAL SUPERNATANT (MG/L) = 142.
TSS, (MG/L)
RETENTION TIME, (HRS)
0
20
40
60
80
100
0
80
160
240
320
400

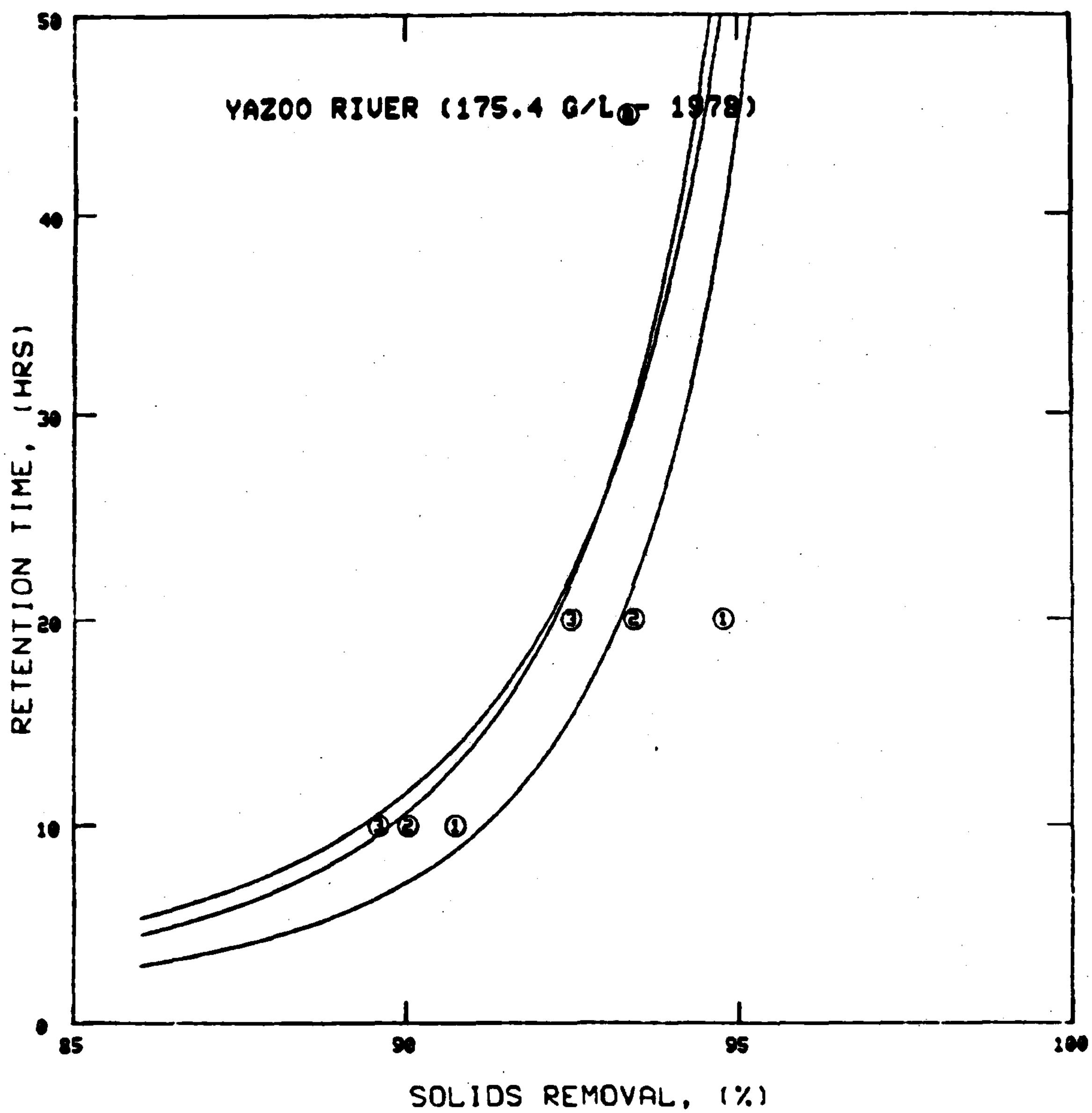

YAZOO RIVER (1978)
COMPRESSION SETTLING TEST RESULT
C = 199.6 X(T)XX.1022
RXX2 = .9096
TIME, T, (DAYS)
SOLIDS CONCENTRATION, C, (G/L)

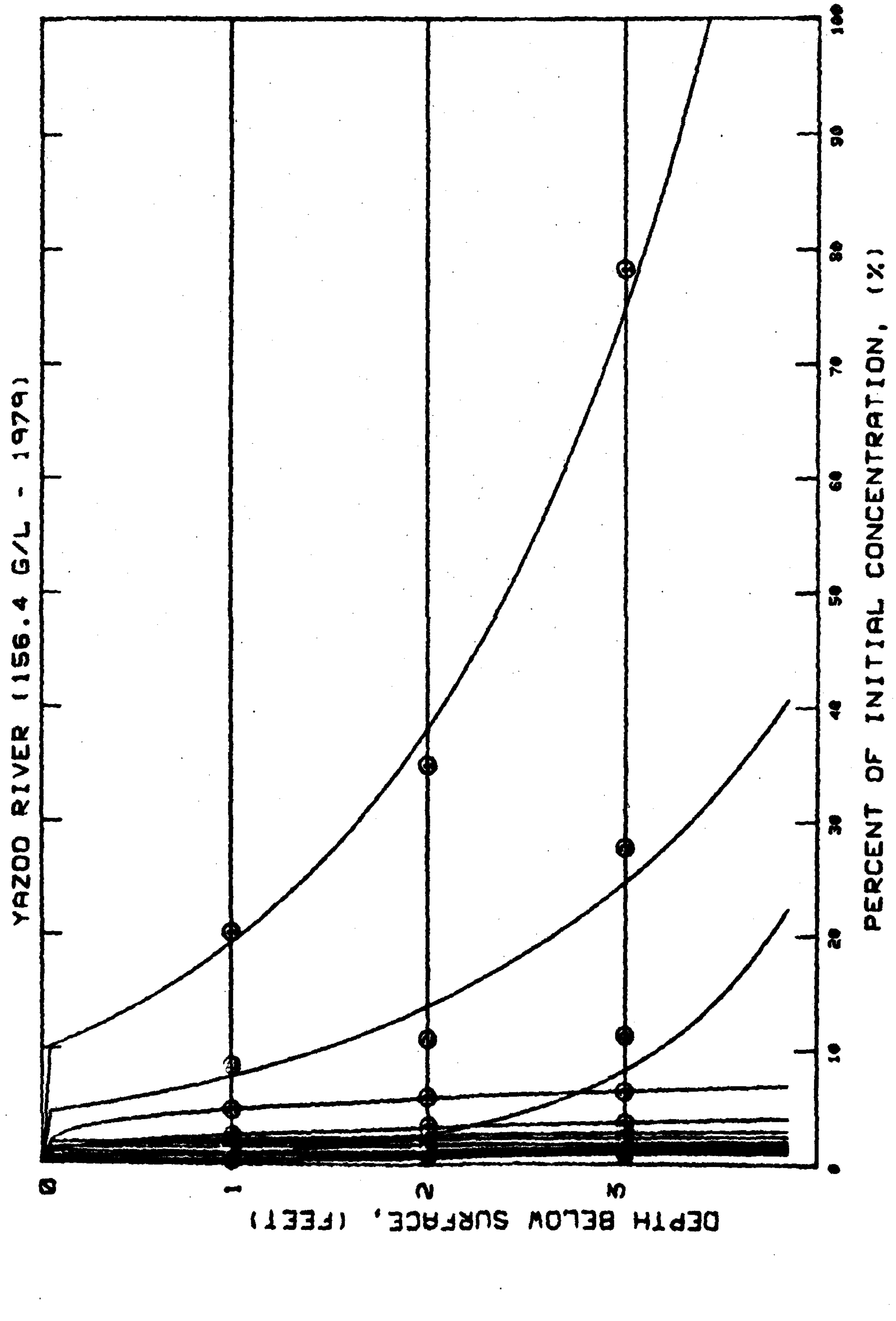


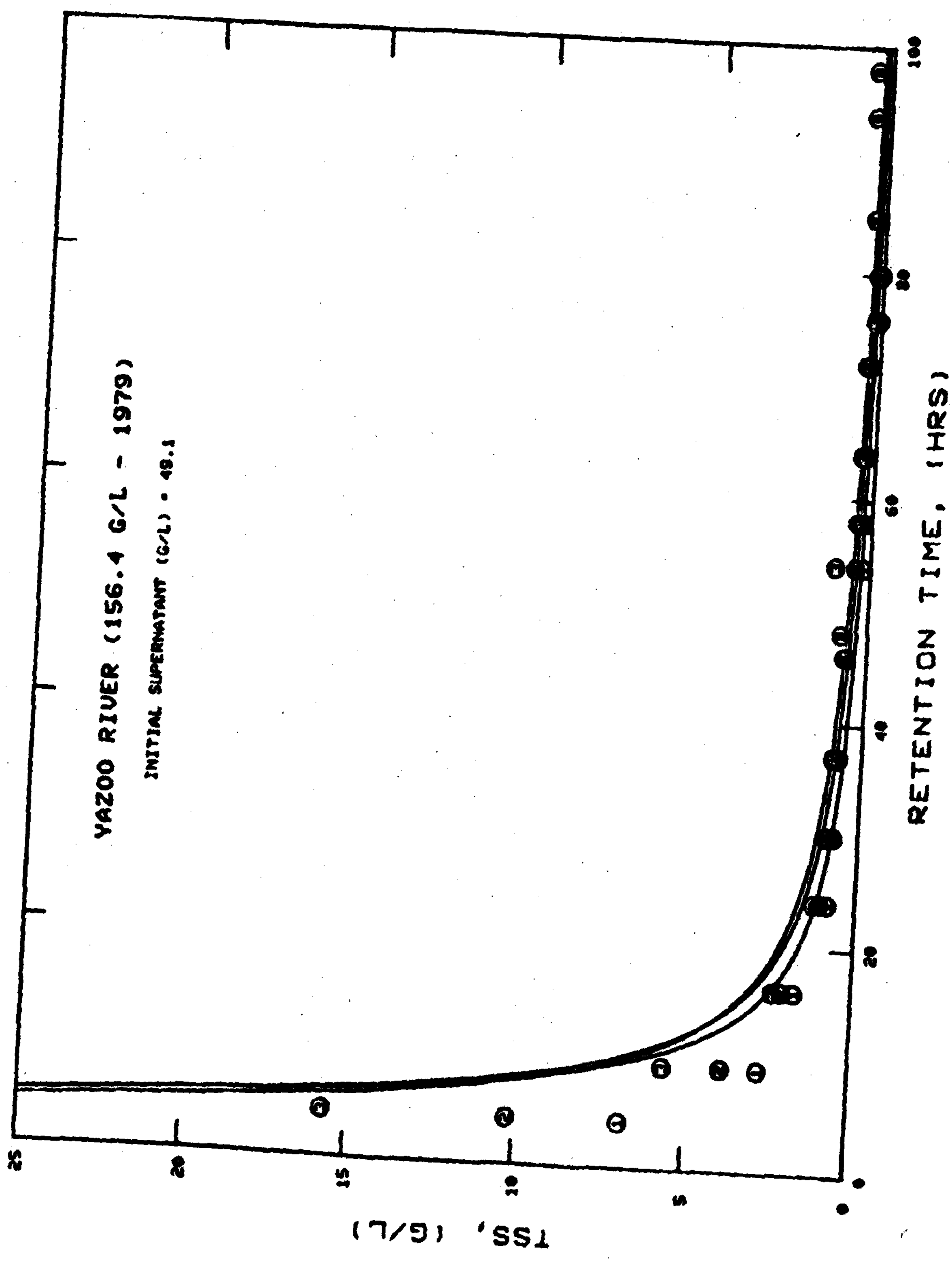
YAZOO RIVER (175.4 G/L - 1978)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3

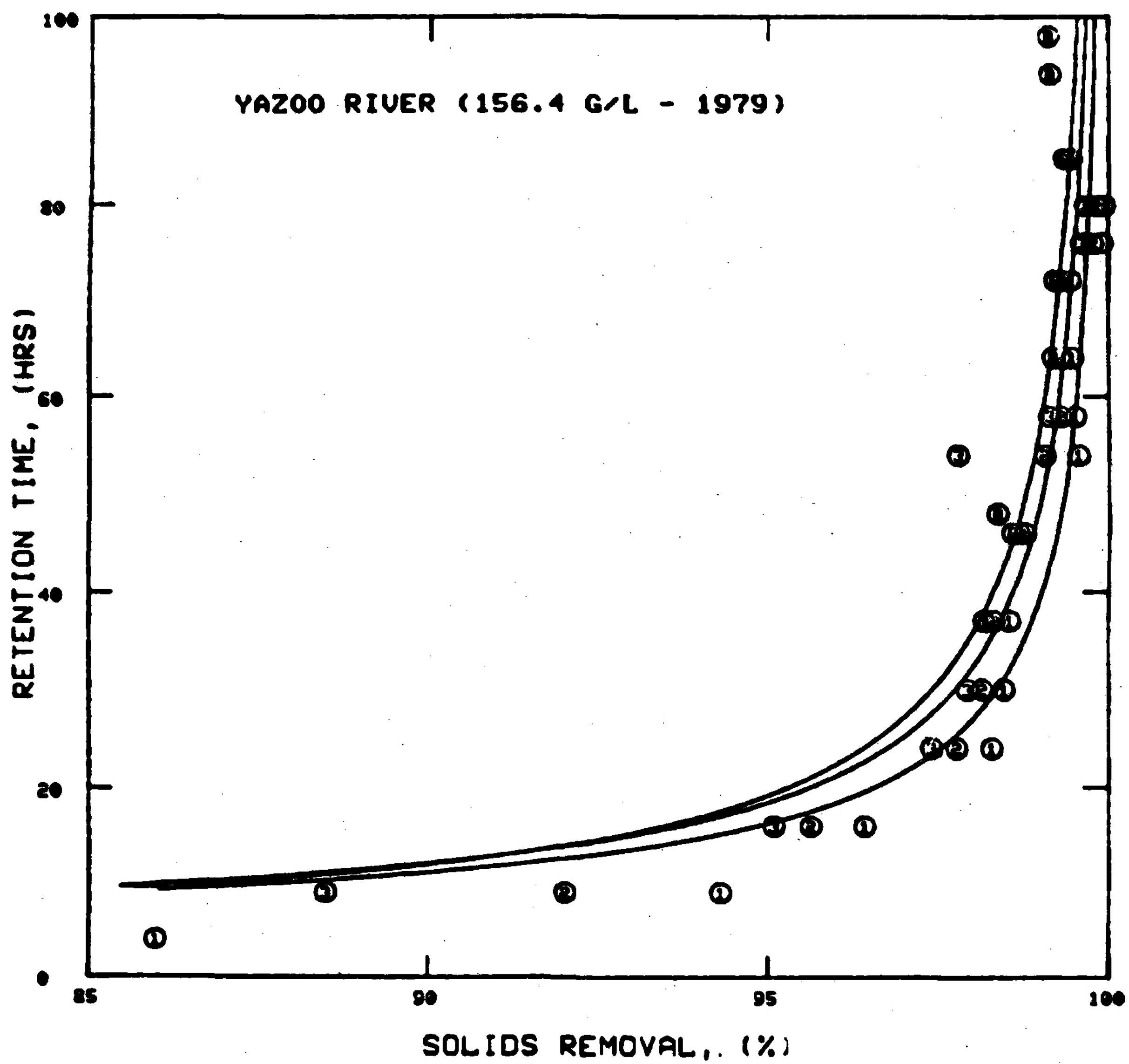


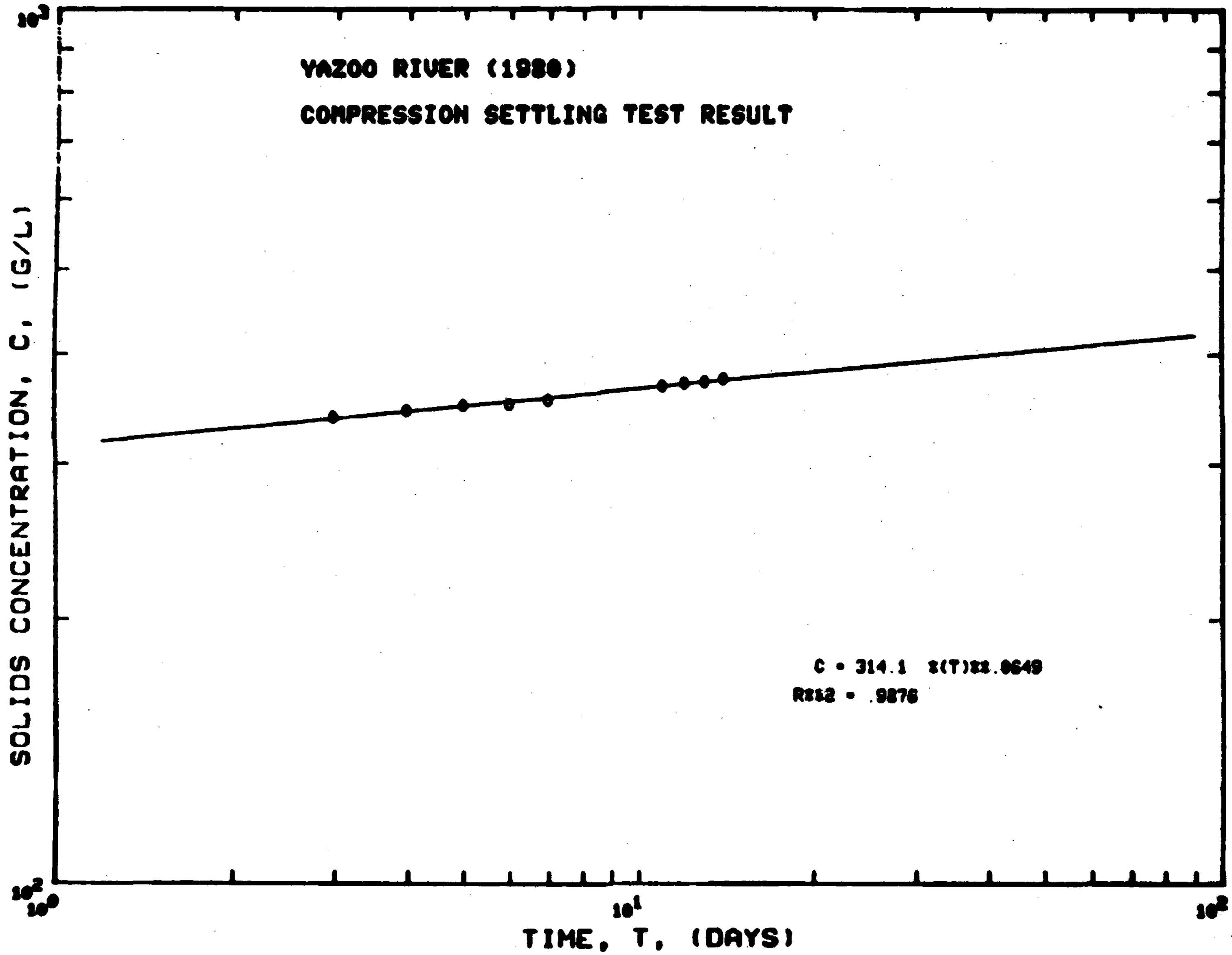
YAZOO RIVER (175.4 G/L - 1978)
INITIAL SUPERNATANT (G/L) = 174.
TSS, (G/L)
RETENTION TIME, (HRS)
0
25
50
75
100
125
0
10
20
30
40
50


YAZOO RIVER (175.4 G/L - 1978)
RETENTION TIME, (HRS)
SOLIDS REMOVAL, (%)
0
10
20
30
40
50
85
90
95
100
①
②
③

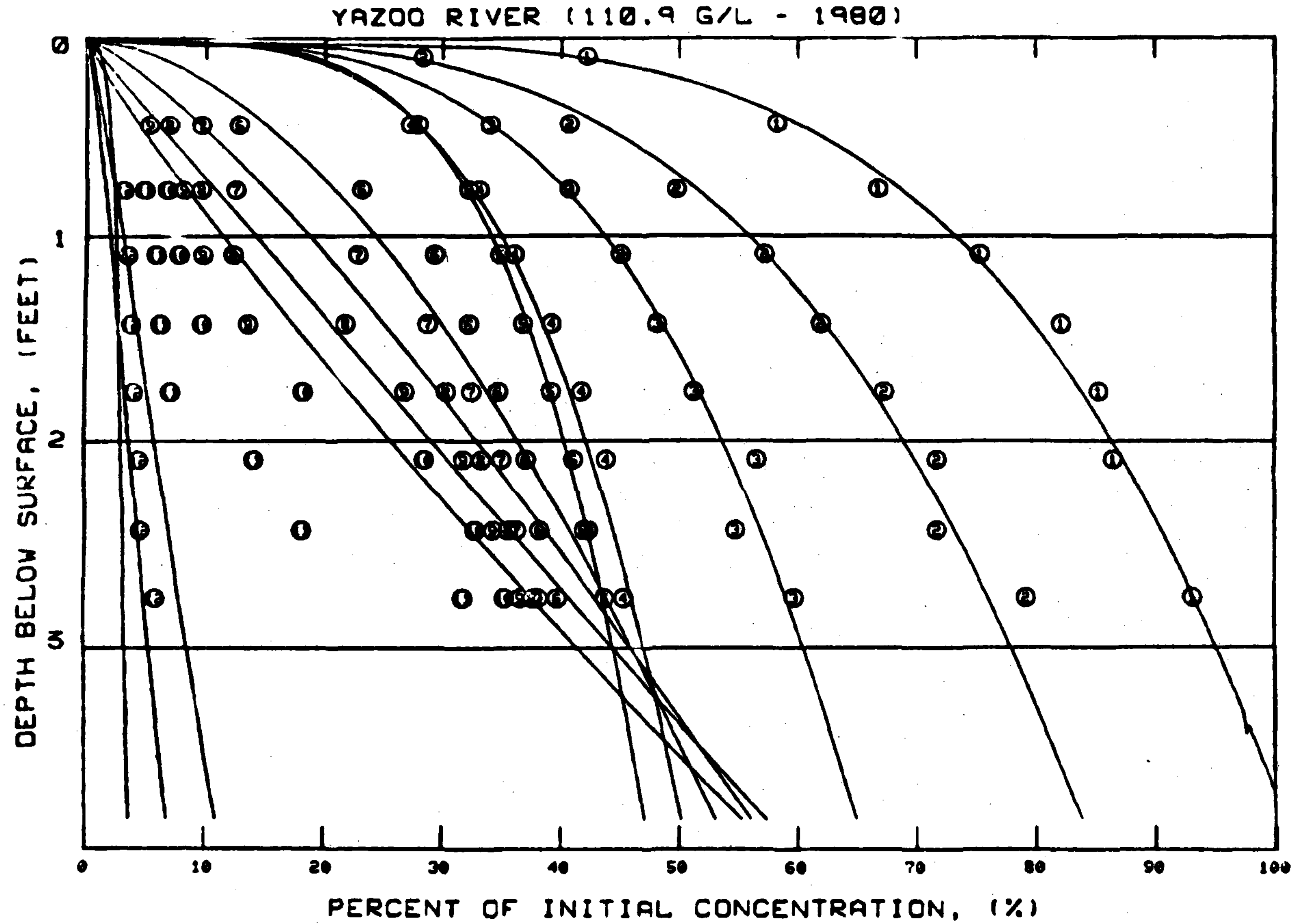

YAZOO RIVER (156.4 G/L - 1979)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100

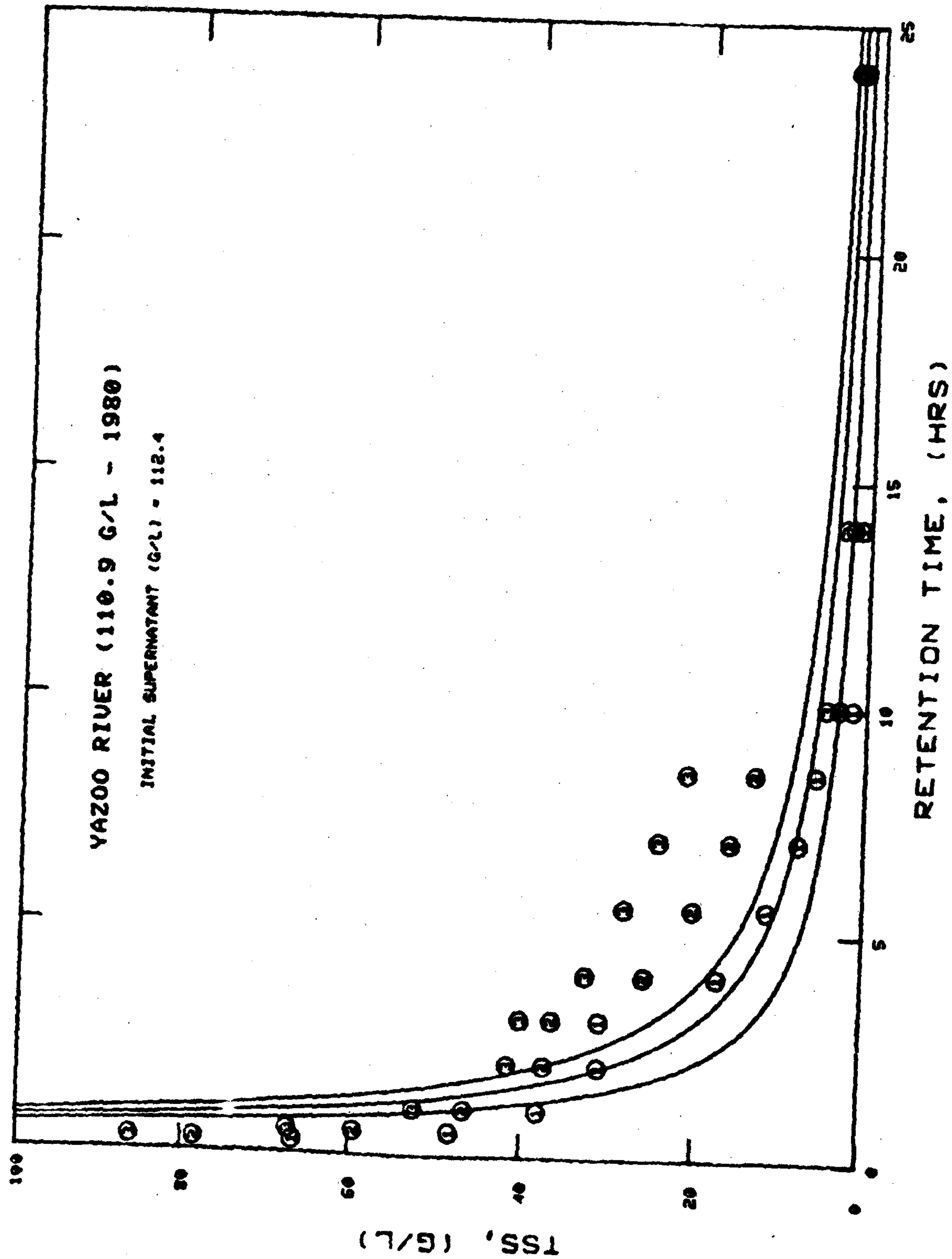

YAZOO RIVER (156.4 G/L - 1979)
INITIAL SUPERNATANT (G/L) = 49.1
RETENTION TIME, (HRS)
TSS, (G/L)
0
20
40
60
80
100
0
5
10
15
20
25

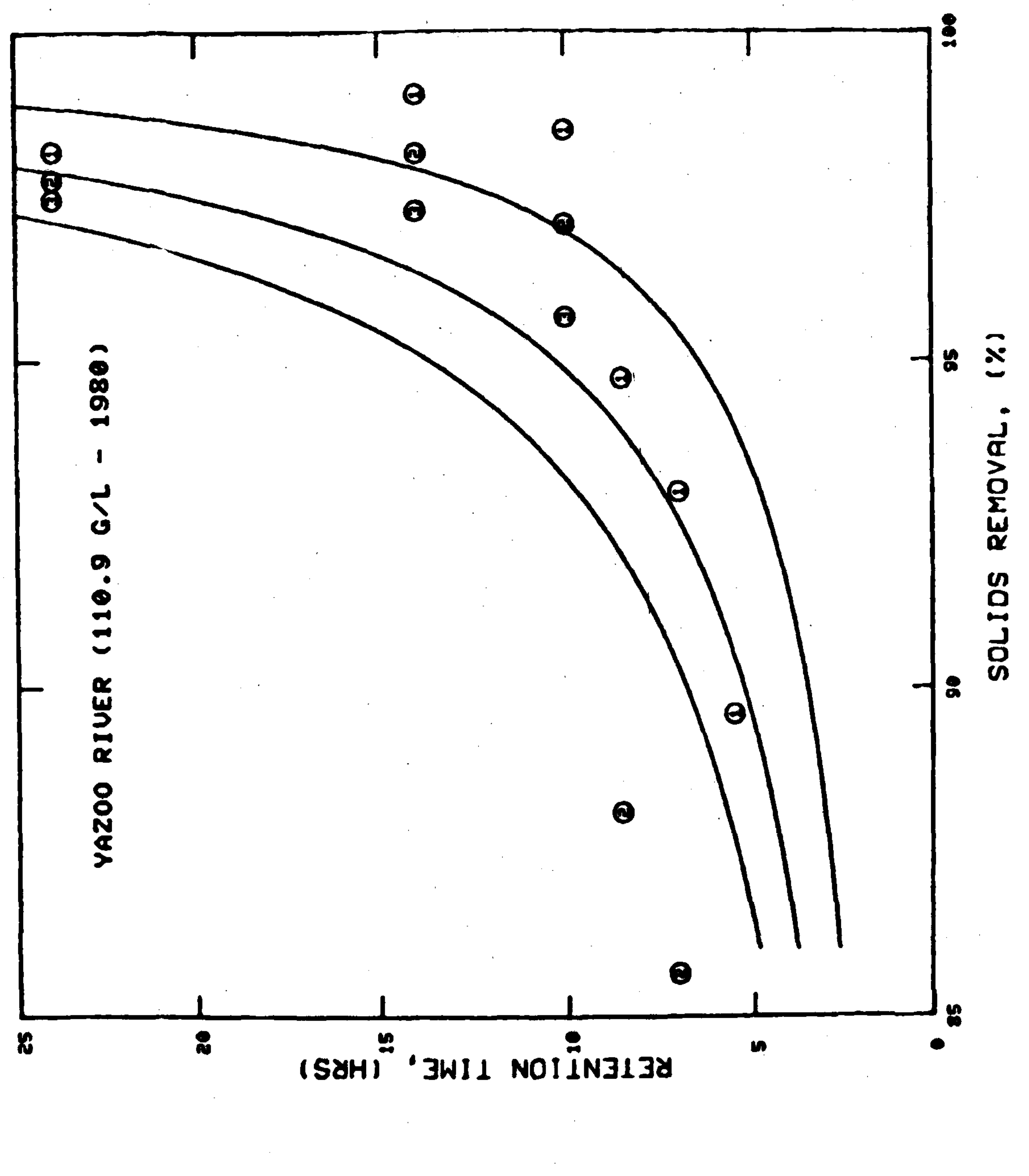

YAZOO RIVER (156.4 G/L - 1979)
RETENTION TIME, (HRS)
SOLIDS REMOVAL, (%)
100
80
60
40
20
0
85
90
95
100



YAZOO RIVER (1980)
COMPRESSION SETTLING TEST RESULT
C = 314.1 *(T)**.0649
R**2 = .9876
SOLIDS CONCENTRATION, C, (G/L)
TIME, T, (DAYS)

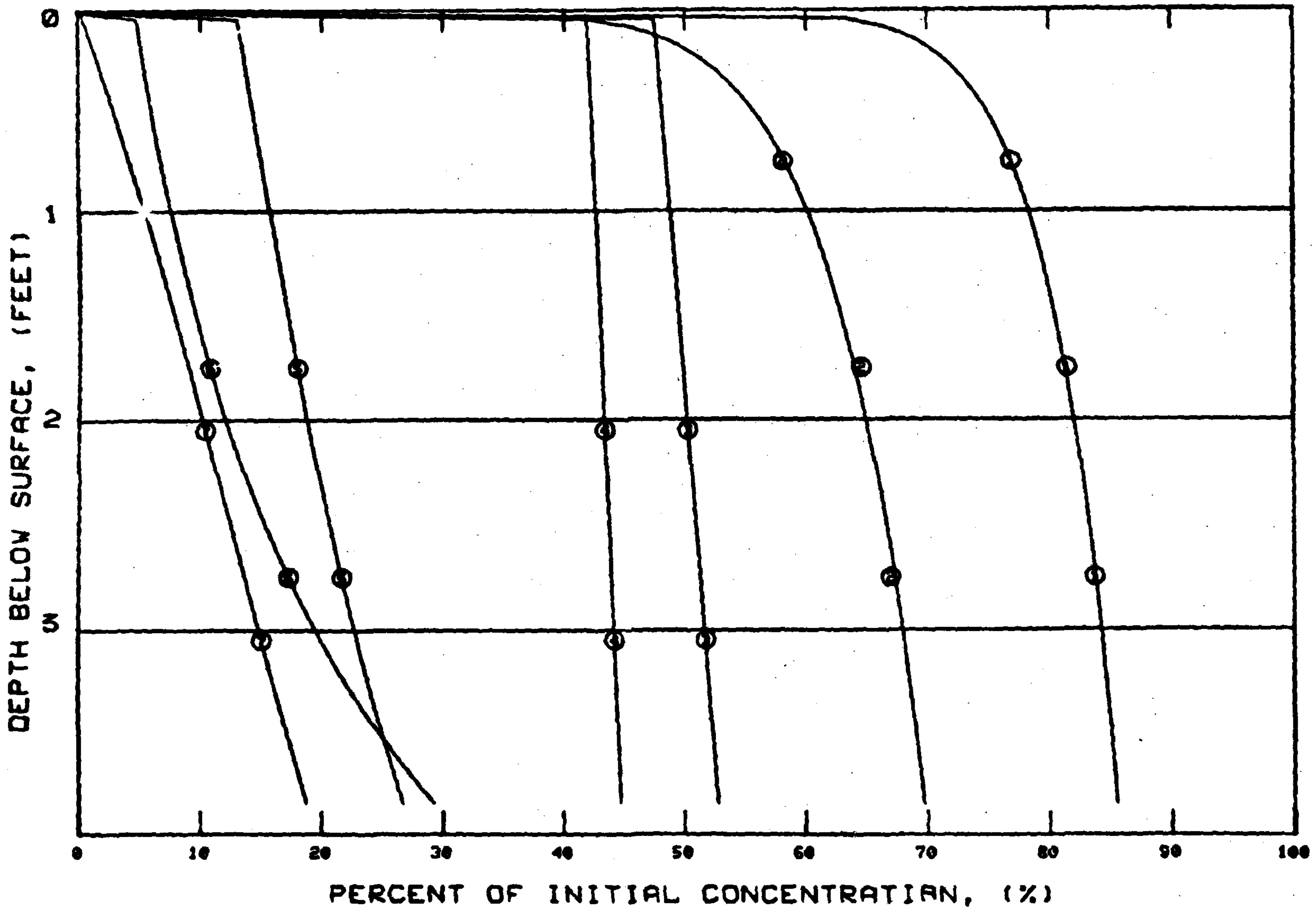

YAZOO RIVER (110.9 G/L - 1980)
DEPTH BELOW SURFACE, (FEET)
PERCENT OF INITIAL CONCENTRATION, (%)
0
1
2
3
0
10
20
30
40
50
60
70
80
90
100

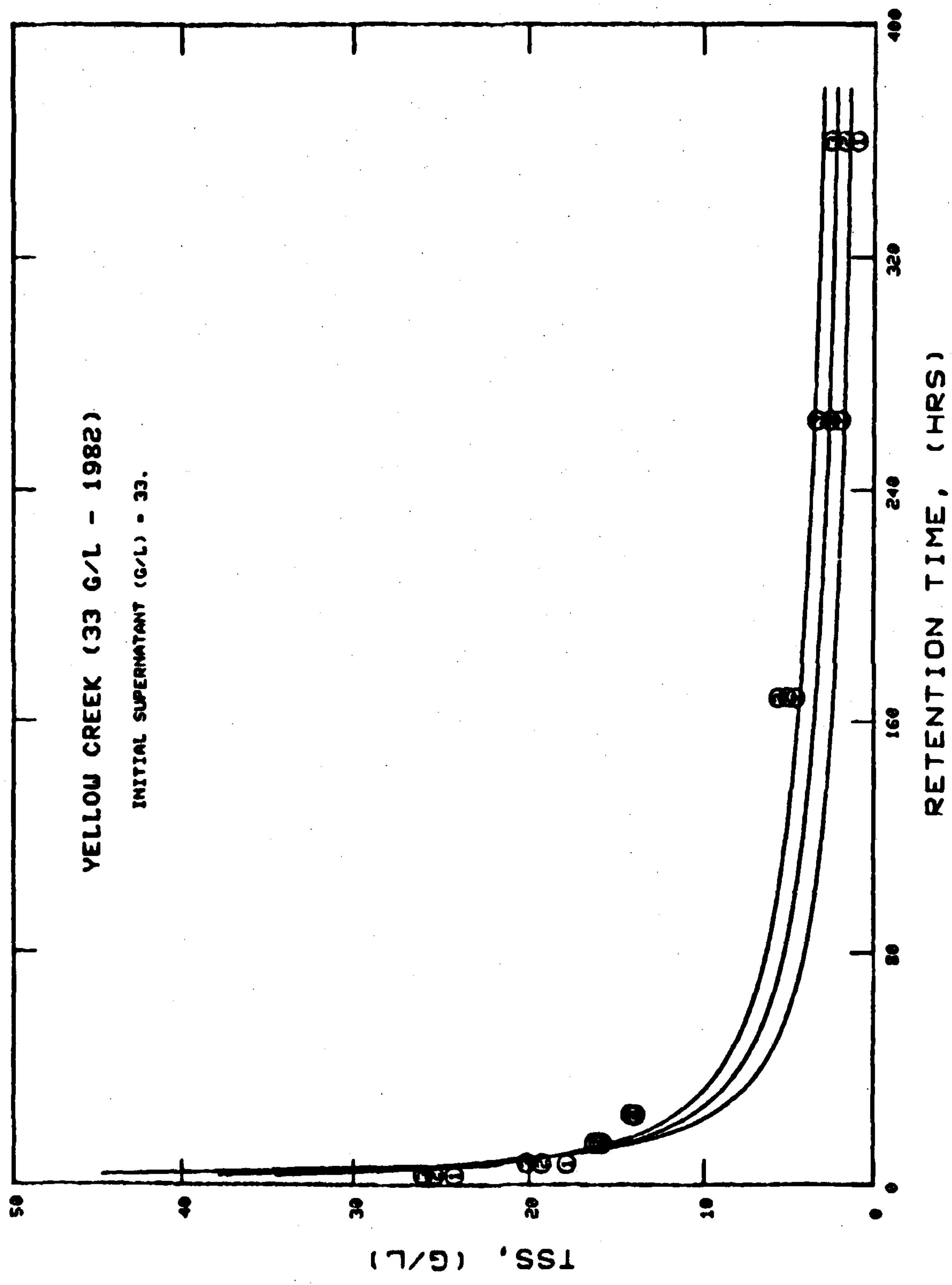

YAZOO RIVER (110.9 G/L - 1980)
INITIAL SUPERNATANT (G/L) = 112.4
RETENTION TIME, (HRS)
TSS, (G/L)
0
5
10
15
20
25
0
20
40
60
80
100



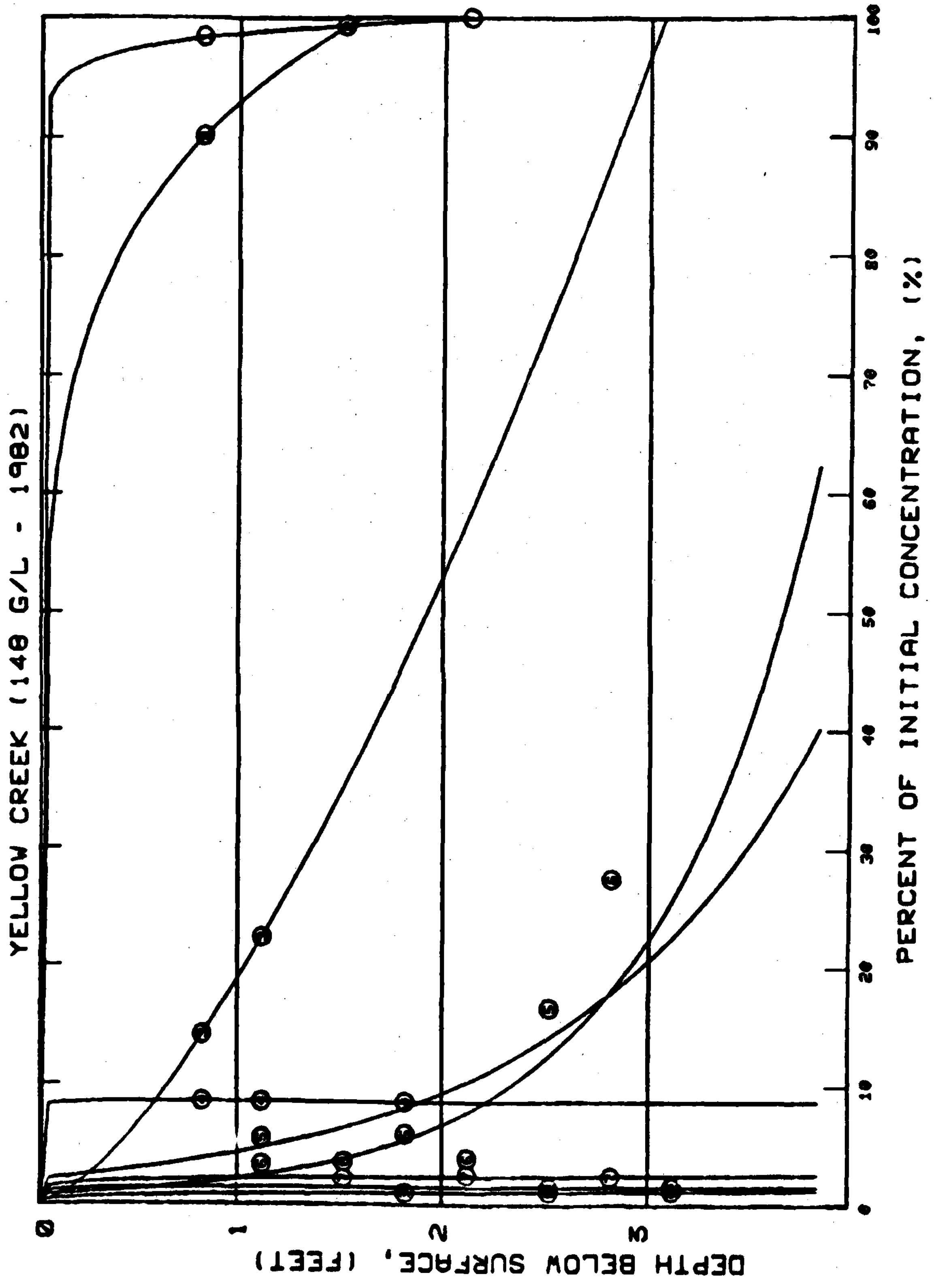
YAZOO RIVER (110.9 G/L - 1980)
RETENTION TIME, (HRS)
SOLIDS REMOVAL, (%)

YELLOW CREEK (33 G/L - 1982)

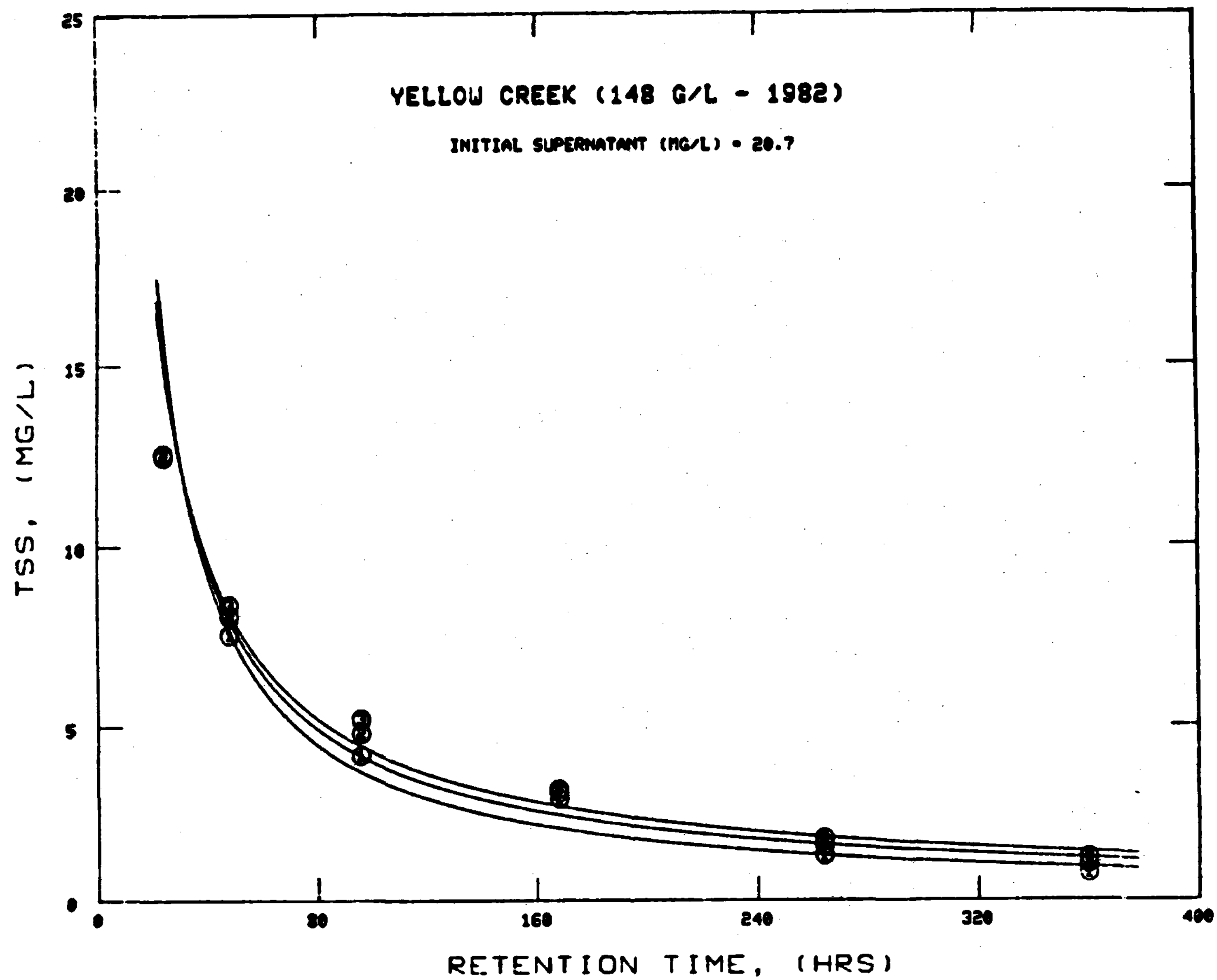




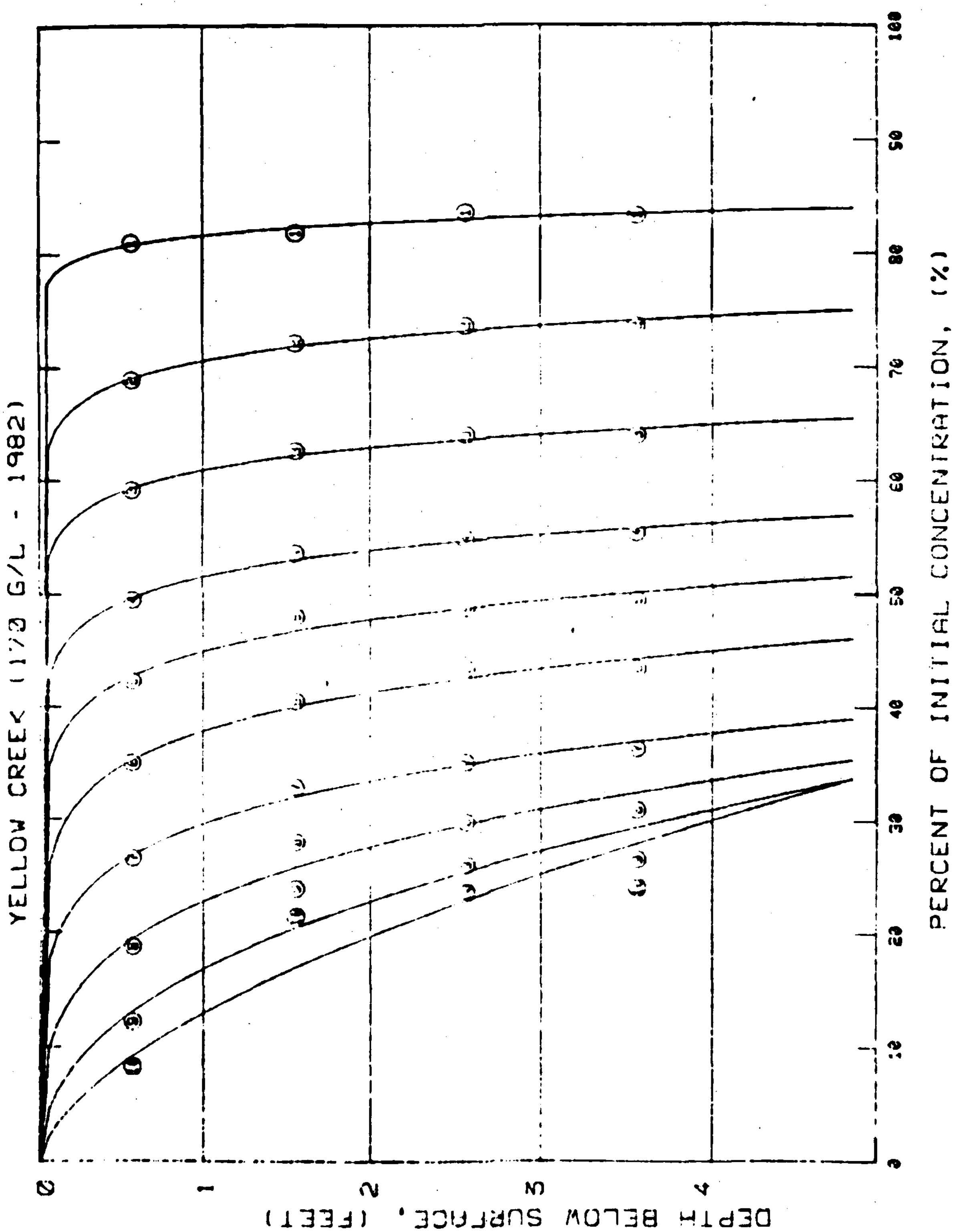
YELLOW CREEK (33 G/L - 1982)
INITIAL SUPERNATANT (G/L) = 33.
RETENTION TIME, (HRS)
TSS, (G/L)
0
80
160
240
320
400
0
10
20
30
40
50

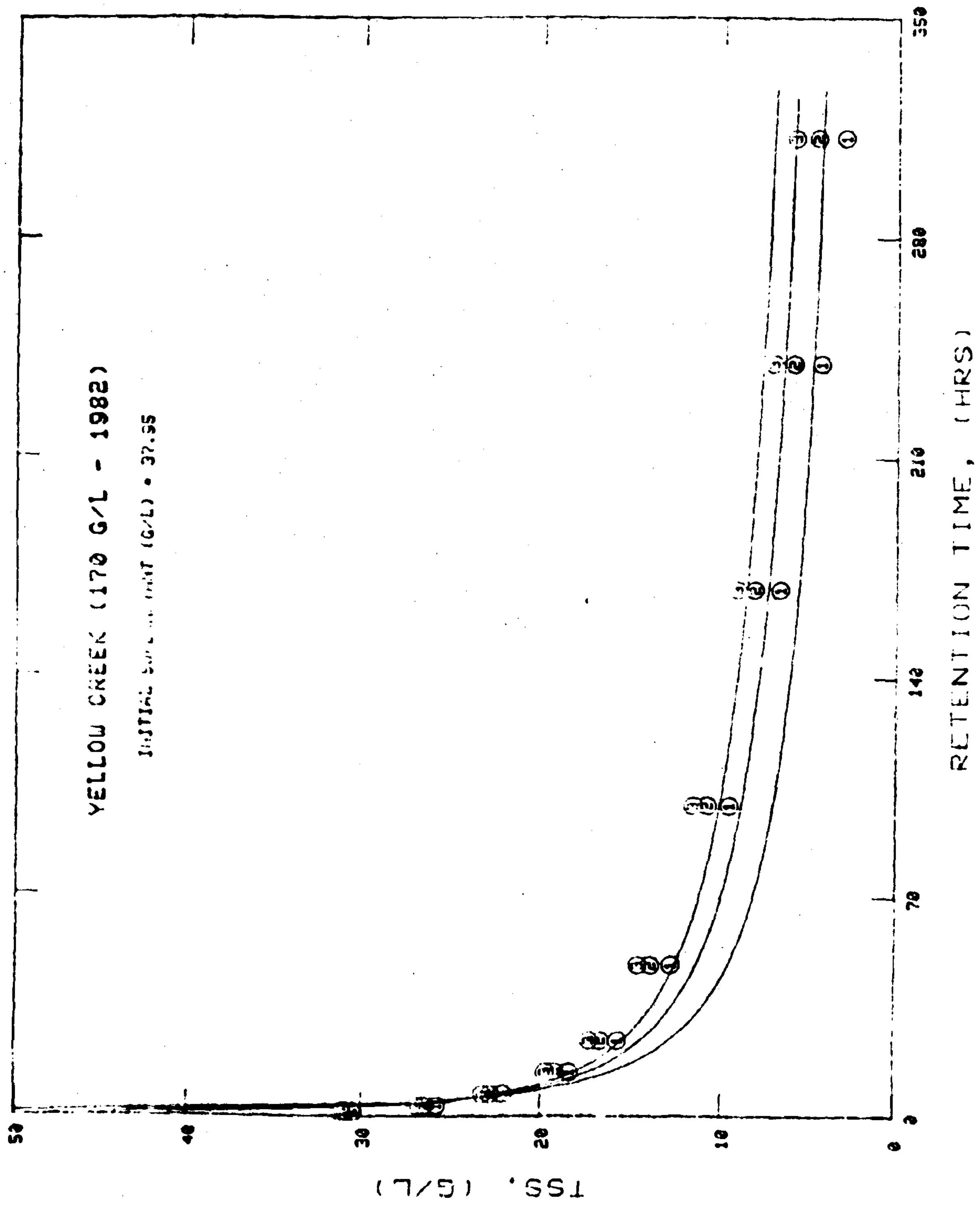


YELLOW CREEK (148 G/L - 1982)
PERCENT OF INITIAL CONCENTRATION, (%)
0
10
20
30
40
50
60
70
80
90
100
DEPTH BELOW SURFACE, (FEET)
0
1
2
3



YELLOW CREEK (148 G/L - 1982)
INITIAL SUPERNATANT (MG/L) = 20.7
TSS, (MG/L)
25
20
15
10
5
0
80
160
240
320
400
RETENTION TIME, (HRS)


YELLOW CREEK (170 G/L - 1982)
PERCENT OF INITIAL CONCENTRATION, (%)
DEPTH BELOW SURFACE, (FEET)


YELLOW CREEK (170 G/L - 1982)
37.55
RETENTION TIME, (HRS)
TSS, (G/L)
0
70
140
210
280
350
0
10
20
30
40
50